Am J Transl Res 2025;17(5):3862-3874
www.ajtr.org /ISSN:1943-8141/AJTR0161753

Original Article

Application of a self-made liver suspension device in 3D laparoscopic non-anatomical resection of liver segment VI and VII tumors

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Received November 5, 2024; Accepted May 11, 2025; Epub May 15, 2025; Published May 30, 2025

Abstract: Objective: To evaluate the efficacy of a novel self-designed liver suspension device in three-dimensional (3D) laparoscopic non-anatomical (NAR) resection for tumors in hepatic segments VI and VII. Methods: Clinical records of 79 patients undergoing NAR resection of hepatic segments VI and VII at the Second Hospital of Hebei Medical University (June 2016-December 2021) were retrospectively reviewed. Patients were stratified into the Suspension Device Laparoscopic Group (SDLG), utilizing the self-designed suspension device for 3D-guided resection, and the Conventional Laparoscopic Group (CLG). Statistical analyses comprised two-sample t-tests, chi-square tests, and Log-rank tests. Perioperative outcomes including surgical time, hepatic pedicle occlusion time, intraoperative blood loss, postoperative hospital stay, drainage tube removal time, time to ambulation, postoperative flatus recovery, and complications (pleural effusion, ascites, bile leakage, wound infection/liquefaction/effusion) were compared. Postoperative hepatic functional recovery (Child-Pugh classification) and 1-/3-year survival rates were assessed. Results: The SDLG demonstrated significantly shorter surgical time, reduced intraoperative blood loss, and abbreviated hepatic pedicle clamping time compared to the CLG. Postoperative hepatic functional recovery, as assessed by Child-Pugh classification, was accelerated in the SDLG cohort, with a higher proportion achieving baseline function earlier than the CLG. Complication rates, including pleural effusion, ascites, and bile leakage, were markedly lower in the SDLG, while no significant differences were observed in hospitalization duration, ambulation initiation, or flatus recovery. Survival analysis revealed the 1-/3-year survival rate of SDLG was higher than that of CLG. Conclusion: The self-designed liver suspension device enhances the safety and efficiency of 3D laparoscopic NAR resection for hepatic segment VI and VII tumors by minimizing operative trauma, reducing mechanical injury risks, and promoting postoperative hepatic functional recovery. Its application is associated with fewer procedure-related complications to conventional techniques, and increased survival rate. These advantages underscore its potential as a valuable innovation in minimally invasive liver surgery, meriting further clinical validation and integration with complementary technologies to refine surgical precision and outcomes.

Keywords: Three-dimensional laparoscopy, hepatic segments VI and VII, liver suspension device, hepatic neoplasm, laparoscopic liver resection

Introduction

Driven by continuous advancements in laparoscopic instruments and techniques, LLR has gained increasing prominence for both benign and malignant liver tumors due to its minimally invasive advantages [1, 2]. The concurrent evolution of endoscopic technology and digital connectivity has accelerated the global adoption of laparoscopic approaches, with three-dimensional (3D) laparoscopy emerging as a transformative tool in complex hepatobiliary-pancreatic surgeries across major medical centers [3, 4]. Particularly challenging NAR resections of posterosuperior liver segments (I, VI, VII, and VIII) present unique technical hurdles due to their

https://doi.org/10.62347/FEMB3665

deep anatomical positioning and intricate vascular relationships [5, 6]. This challenge intensifies when tumors are around critical vasculature such as the inferior vena cava and hepatic veins, where optimal visual exposure becomes paramount for safe dissection. Inadequate visualization during VI/VII segment resections may precipitate increased intraoperative hemorrhage and conversion rates, particularly among surgeons with limited experience [7].

Modern 3D laparoscopic systems, featuring articulating four-way flexible endoscopes, offer revolutionary advantages over conventional 2D platforms through enhanced depth perception and spatial resolution [8]. These stereoscopic capabilities enable precise tissue differentiation, facilitating meticulous vascular dissection and suture-intensive procedures with improved instrument control [9-12]. Continuous innovations in surgical methodology coupled with novel auxiliary devices have progressively expanded the boundaries of minimally invasive liver surgery [13].

Current surgical paradigms categorize hepatic resections as anatomical or NAR, with ongoing debate regarding their oncological equivalence in hepatocellular carcinoma management [14]. While NAR offers technical accessibility for resource-limited settings, definitive evidence supporting 3D laparoscopic NAR for VI/VII segment tumors remains scarce [15]. Traditional exposure techniques involving manual liver retraction frequently prove suboptimal, potentially compromising hemostatic control [16, 17].

This retrospective analysis examines 79 consecutive cases of 3D laparoscopic NAR for VI/VII segment tumors at our tertiary center (June 2016-December 2021), introducing an innovative liver suspension device that enhances surgical exposure while minimizing parenchymal injury. Comparative outcomes between conventional and device-assisted approaches aim to establish an evidence base for optimizing minimally invasive liver resection techniques.

Methods

General information

A retrospective analysis was performed on clinical data from 79 patients undergoing non-anatomical (NAR) resection of hepatic segments VI and VII at the Second Hospital of Hebei Medical University between June 2016 and December 2021. Patients were stratified into two cohorts based on surgical approach: the Suspension Device Laparoscopic Group (SDLG, n = 45) and the Conventional Laparoscopic Group (CLG, n = 34). Data were extracted from de-identified electronic medical records. The study protocol received approval from the Institutional Ethics Committee (No. 2023-R345) and complied with the ethical tenets of the Declaration of Helsinki. Written informed consent was procured from all participants and legal guardians, encompassing the following provisions: 1) disclosure of anonymized data utilization for research objectives; 2) voluntary enrollment with unrestricted withdrawal rights; 3) substitution of direct identifiers with unique study codes and restriction of datasets to clinically pertinent variables to minimize re-identification hazards.

Inclusion and exclusion criteria

Inclusion criteria: a) Favorable overall clinical status with capacity to tolerate operative interventions; b) Diagnosis of benign or malignant lesions within hepatic segments VI or VII, confirmed via medical history, clinical evaluation, and imaging modalities; c) Maximum tumor diameter ≤ 10 cm; d) Child-Pugh liver function classification A or B (compensated hepatic reserve); e) Absence of intrahepatic/distant metastatic disease or vascular/biliary tumor thrombi (hepatic veins, portal veins, inferior vena cava, or bile ducts); f) No active chronic hepatitis B infection; g) No prior interventional, radiotherapeutic, chemotherapeutic, or ablative therapies; h) Signed informed consent by both patient and legal representatives.

Exclusion criteria: a) Primary tumor dimensions exceeding 10 cm or exophytic growth pattern with significant hepatic surface protrusion, precluding safe resection due to spatial constraints or risks of intraoperative tumor rupture/cellular dissemination; b) Elevated tumor surface tension posing rupture risks during manipulation; c) Advanced hepatic cirrhosis necessitating maximal parenchymal preservation while maintaining oncologic resection margins; d) Tumor proximity to major hepatobiliary vasculature or presence of portal/hepatic venous tumor thrombi; e) Preoperative tumor rupture confirmed radiologically or clinically; f) Prior upper abdominal surgical interventions; g) Absolute or relative contraindications to laparoscopic approaches; h) Intraoperative conversion to open laparotomy; i) Advanced disease progression identified during exploratory surgery; j) History of hepatic arterial embolization, radiotherapy, systemic chemotherapy, or radiofrequency ablation.

Surgical methods

Preoperative protocols: Both patient cohorts underwent hepatic function panels and preoperative hematologic assessments. Standard supportive care was administered, with multimodal imaging surveillance utilizing contrast-enhanced computed tomography (CT), magnetic resonance imaging (MRI), electrocardiographic (ECG) monitoring, and echocardiographic evaluation. Advanced perioperative monitoring incorporated real-time 3D hepatic parenchyma reconstruction for intraoperative navigation.

All surgical procedures utilized general anesthesia with endotracheal intubation. Peripheral venous access was established prior to anesthetic induction, with continuous electrocardiographic monitoring of hemodynamic parameters. The induction sequence involved titrated administration of intravenous anesthetic agents, analgesic medications, and neuromuscular blocking agents, effecting transition from full consciousness to an unconscious state within minutes and suppression of spontaneous respiration from 16-20 breaths per minute to ventilatory arrest, followed by airway instrumentation. Endotracheal tube placement was facilitated under direct visualization using rigid laryngoscopy or flexible bronchoscopic guidance, with proper positioning confirmed before tube fixation. Mechanical ventilation ensured adequate oxygenation throughout the procedure. Anesthetic maintenance required ongoing titration of pharmacological agents based on hemodynamic surveillance. Upon surgical completion, anesthetic agents were ceased, initiating the emergence phase characterized by gradual return of consciousness. Postoperative monitoring protocols included continuous hemodynamic assessment and intravenous fluid resuscitation to maintain physiological stability.

Conventional laparoscopic group (CLG): Following induction of anesthesia, the patient is in a supine position, with both upper limbs extended 90 degrees and both lower limbs separated 70-80 degrees, forming a "large" shape. The mirror holder stands between the patient's lower limbs. The right shoulder and back were elevated 45-60° using a soft cushion and the right upper limb was abducted and fixed to facilitate the dissection and dissociation of the right half of the liver. Sterile drapes were applied and periodically disinfected (**Figure 1A**). A five-port technique was used, with a 10 cm trocar inserted above the umbilicus, to the right of the rectus abdominis muscle, followed by the insertion of a 3D laparoscope. Under direct visualization, a 12 cm trocar was placed 5 cm below the right anterior axillary line, and a 5 mm trocar was placed 5 cm below the right posterior axillary line. A 10 mm trocar was inserted below the xiphoid process, and a 5 mm trocar was placed 2 transverse fingers above the umbilicus as an auxiliary hole. Using an ultrasonic knife, the circular ligament, falciform ligament, right triangular ligament, hepatorenal ligament, and right coronary ligament, were cut to fully free the right liver, an assistant pulled the right liver to expose liver segments VI and VII. The conventional approach for exposing tumors in segments VI and VII of the liver involves an assistant utilizing laparoscopic non-traumatic forceps to retract the right lobe of the liver to the left, or by suturing the right lobe and pulling the liver to the left, thereby facilitating tumor exposure. The tail end of the 12Fr urethral catheter was used to wrap around the hepatoduodenal ligament forming a circular blocking device structure surrounding the first hepatic hilum (**Figure 1B**, **1C**). The blocking band was tightened to the first hepatic portal, blocking the first hepatic portal intermittently. Intermittent occlusion of the hepatic pedicle was performed for 15 minutes followed by a 5-minute release. The planned incision line was outlined using an electrocautery hook. The ultrasonic scalpel was used to slowly dissect the liver tissue along the planned incision line. Hem-o-lok clips were used to transect the vessels entering the tumor. The incision was enlarged below the xiphoid process to retrieve the specimen, which was placed in a bag until the tumor was completely excised. The wound surface was irrigated, and if active bleeding from liver segments was noted, electrocautery

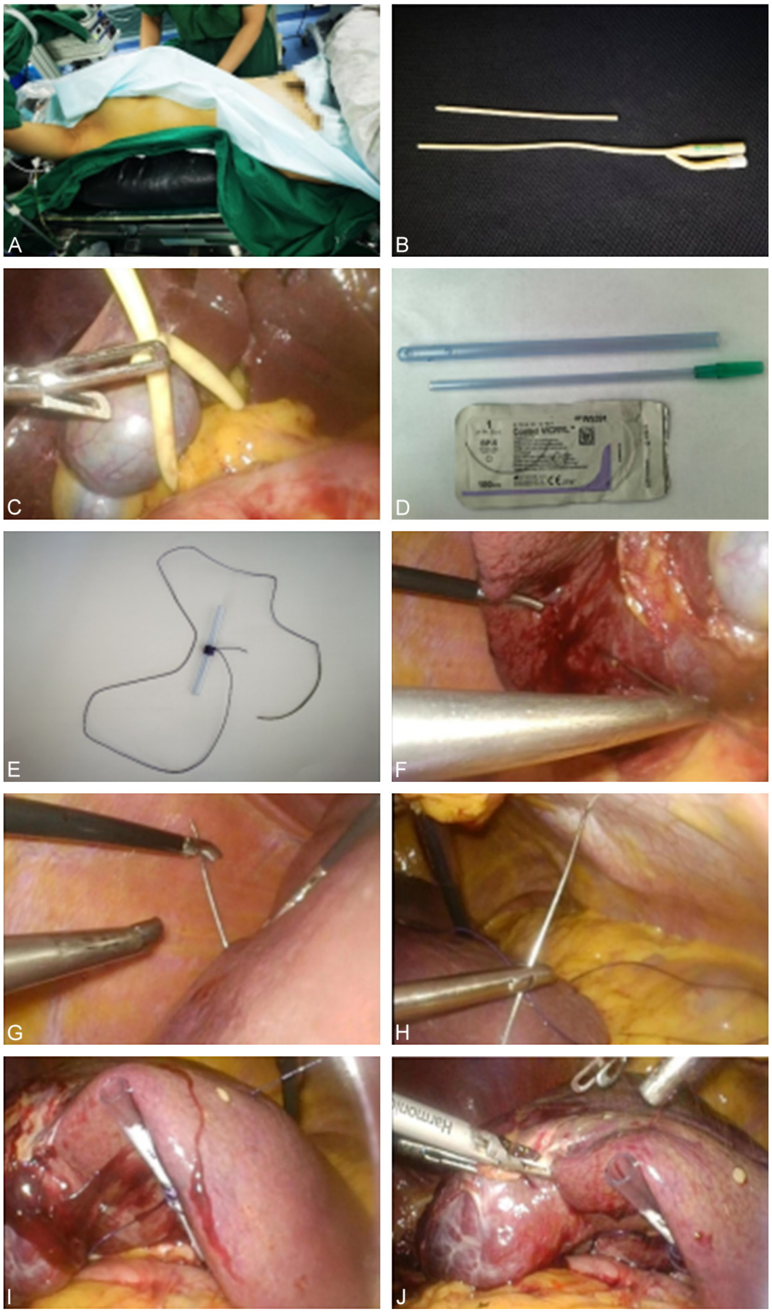

Figure 1. The operation related operation and device schematic diagram of the CLG and the SDLG. A. Surgical positioning. B. Hepatic pedicle clamping device. C. Hepatic pedicle clamping process. D-H. Self-Made Simple liver suspension device. F-I. Liver suspension process. J. Tumor resection using an ultrasonic scalpel. Note: Surgical Positioning, Hepatic Pedicle Clamping Device, and Self-Made Liver Suspension Device for Liver Retraction.

or 3-0 or 4-0 sutures were used for hemostasis. After checking for active bleeding or bile leakage, hemostatic materials were placed on the liver wound, and two abdominal drains were placed under the right diaphragm and liver wound. Finally, the abdominal skin incision was closed using absorbable sutures or skin adhesive.

Suspended device laparoscopic group (SDLG): Given the friable nature of hepatic parenchyma, excessive traction can cause hemorrhage, while inadequate traction compromises exposure of segments V and VII. Surgical steps mirrored the CLG except for utilization of a customized liver suspension device (**Figure 1B**), other surgeries were similar to the traditional laparoscopic group. The creation and use of the suspension device are as follows (**Figure 1D-J**): A 3-4 cm segment of rigid plastic tubing (**Figure 1D**, **1E**) was used. A ETHICON (4 Ph. Eur) Coated VICRYL™ (polyglactin 910) Suture was taken. We took a plastic hard rod (usually we used a plastic disposable suction tube, and cut it, taking a small section about 3-4 cm length), and we used the suture to firmly tie the middle of the hard rod to prevent slipping. This forms a self-made suspension base, forming a "T" shape with the suture. We placed this self-made liver suspension device into the abdominal cavity, clamped the needle with the needle holder, inserted the needle from the visceral surface between liver segments V and VI, extracted the needle from the diaphragmatic surface of the liver, and extracted the liver needle from the abdominal wall of the left costal margin. Pulling the suture, so that the right liver is pulled to the left, fully exposing the tumors in segments VI and VII (so, the assistant doesn't need to pull the liver). This technique facilitated optimal exposure of segments VI and VII while liberating the assistant's hands for instrument manipulation.

Postoperative care considerations: 1) Monitoring: Close observation of the patient's vital signs, including blood pressure, heart rate, and respiratory rate. Vigilant assessment of indications of postoperative hemorrhage, infection, or other complications. Removal of the endotracheal tube promptly upon confirmation of sufficient respiratory function recovery. 2) Analgesia protocol: Postoperative pain management tailored according to the patient's reported discomfort levels. Appropriate analgesics administered promptly to ensure optimal comfort. 3) Dietary progression: Incremental reintroduction of oral intake as per clinical directives, initiated with a liquid diet, advancing to semi-solid foods, progressing to a regular diet. Avoid fatty or spicy foods to mitigate gastrointestinal distress. 4) Mobilization: Adhere to physician-guided activity regimens. Refrain from strenuous exertion and excessive fatigue while preventing prolonged immobility. Implementation of ankle pump exercises during bed rest diminishes thrombotic risk. 5) Wound management: Maintaining wound cleanliness and dryness, performing regular dressing changes, and monitoring for infectious manifestations. Ensuring optimal wound healing and preempt complications. 6) Pharmacotherapy: Complying with prescribed regimens for antibiotics, analgesics, and adjunct medications to prevent infection and alleviate pain. 7) Follow-up protocol: Systematic scheduling of postoperative evaluations helps to assess recovery progress. Conducting necessary diagnostic investigations to detect and address potential complications. 8) Individualized modifications: Customization of clinician's care strategies based on patient-specific clinical profiles.

Observation metrics

Hepatic functional recovery: All patients underwent the Child-Pugh classification assessment within a 48-hour preoperative window to establish baseline hepatic functional status [18]. Postoperatively, on the 7th day (or prior to discharge), a reassessment was conducted using the Child-Pugh classification to evaluate hepatic functional recovery.

Operative parameters: Document and analyze surgical time [19], hepatic pedicle occlusion duration [20], and intraoperative blood loss [21] across both cohorts. Hepatic pedicle occlusion primarily denotes hepatic inflow blockade, with primary hepatic pedicle occlusion being the predominant technique. Modulate primary hepatic pedicle occlusion intervals contextually to minimize hemorrhage, limiting each occlusion episode to ≤ 15 minutes with ≥ 5-minute reperfusion intervals.

Postoperative documentation: Record hospitalization duration [22], drainage tube removal timing [23], postoperative flatus resolution [24], and ambulation initiation [25].

Complication evaluation: Apply the Clavien-Dindo classification system to catalog complications occurring within 3 postoperative months [26]. Common sequelae post-hepatic tumor resection including pleural effusion, ascites, wound dehiscence, biliary leakage, surgical site infection, and seroma formation.

Mortality statistics: 1- and 3-year outcomes: to evaluate the self-engineered hepatic suspension device for 3D laparoscopic hepatectomy (SDLG) versus conventional 3D laparoscopic hepatectomy (CLG) in reducing mortality risk, a Log-rank test was used to compare survival curves and determine significance in 1- and 3-year survival rates. Survival analysis employed Kaplan-Meier methodology, with intergroup differences compared using the Log-rank test [27].

Statistical analysis

The present study utilized SPSS 26.0 software for data processing and analytical operations. Continuous variables conforming to a normal distribution were expressed as mean ± standard deviation (Mean ± SD), with intergroup comparisons conducted via independent samples t-test. Categorical variables were represented as frequency (percentage), and group disparities were assessed using chi-square test. All statistical analyses adhered to two-tailed testing, with statistical significance defined at $P < 0.05$. For polychotomous categorical variables, multinomial chi-square tests were employed. Survival analysis incorporated Kaplan-Meier methodology for survival curve construction, with between-group differences evaluated via log-rank test, supplemented by hazard ratio (HR) and 95% confidence interval (95% CI) calculations to quantify survival disparities.

Table 1. Comparison of general characteristics between the two groups

Group	CLG (n = 34)	SDLG (n = 45)	t/χ^2	*P*
Age (years)	55.12±11.23	55.04±10.83	0.0320	0.9746
BMI (kg/m^2)	23.42±1.68	23.16±1.61	0.6975	0.4876
Tumor size (cm)	5.94±1.10	5.89±1.00	0.5901	0.5568
Gender			0.1836	0.6683
Men	16	19		
Women	18	26		
Tumor type			0.1350	0.7133
Benign	15	18		
Malignant	19	27		
Preoperative Child grad			0.0041	0.9489
A-level	27	36		
B-level	7	9		
Postoperative Child grad			6.2016	0.0128
A-level	28	44		
B-level	8	1		
Tumor cation			0.2493	0.8828
VI	12	14		
VI/VII	8	10		
VII	14	21		

Note: Data are presented as mean ± standard deviation or count (percentage). *P*-values are based on t-tests or chi-squared tests.

Results

Comparative analysis of baseline characteristics between groups

This study enrolled 79 patients undergoing NAR resection of liver segments VI and VII, stratified into the Suspension Device-assisted Laparoscopic Group (SDLG) and Conventional Laparoscopic Group (CLG). Independent samples *t*-tests revealed no statistically significant intergroup differences in age, BMI, or tumor dimensions (all $P > 0.05$). Categorical variables - including gender distribution, histopathological tumor subtypes, and preoperative Child-Pugh classifications - were analyzed via chi-square tests, demonstrating comparable baseline profiles (gender: $P = 0.6683$; tumor type: $P = 0.7133$; preoperative Child-Pugh: $P = 0.9489$). Notably, postoperative Child-Pugh assessments highlighted superior hepatic functional recovery in the SDLG cohort ($P = 0.0128$). Tumor spatial distribution, evaluated through multinomial chi-square testing, exhibited no locational predilection between groups ($P = 0.8828$). These findings confirm equivalent preoperative baseline characteristics with satisfactory comparability, while underscoring the SDLG's advantage in postoperative hepatic functional restoration (**Table 1**).

Operative and perioperative outcomes

Comparative analysis demonstrated statistically significant reductions in the SDLG cohort for surgical time, hepatic pedicle occlusion time, and intraoperative hemorrhage volume (all $P < 0.05$). Conversely, no intergroup disparities emerged in hospitalization length, ambulation initiation timing, postoperative flatus resolution, or drainage tube removal schedules ($P > 0.05$) (**Table 2**).

Postoperative morbidity profile

Chi-square analysis of surgical complications revealed 16 adverse events in the CLG cohort: pleural effusion ($n = 5$), ascites ($n = 6$), biliary leakage ($n = 3$), incisional infection ($n = 1$), and wound dehiscence ($n = 1$). The SDLG manifested 9 complications: pleural effusion ($n = 2$), ascites ($n = 2$), biliary leakage ($n = 2$), wound infection ($n = 1$), wound dehiscence ($n = 1$), and seroma formation ($n = 1$). The SDLG exhibited

Table 2. The surgical time, hepatic pedicle occlusion time, intraoperative blood loss, hospital stay duration, time to ambulation, postoperative gas expulsion time and postoperative gas expulsion time were compared between the two groups

Group	CLG (n = 34)	SDLG (n = 45)	t	*P*
Surgical time (min)	312.06±51.18	261.00±54.04	4.2531	0.0001
Hepatic pedicle occlusion time (min)	27.06±5.79	23.27±5.67	2.9150	0.0047
Intraoperative blood loss (ml)	267.50±104.43	215.33±76.89	2.5586	0.0125
Hospital stay duration (d)	7.94±1.52	7.71±1.49	0.6735	0.5027
Drainage tube removal time (d)	3.97±1.19	3.71±0.97	1.0695	0.2882
Time to ambulation (d)	1.65±0.60	1.67±0.60	0.1467	0.8838
Postoperative gas expulsion time (d)	1.97±0.72	1.84±0.74	0.7821	0.4366

Note: Data are presented as mean ± standard deviation. *P*-values are based on t-tests.

Table 3. Comparison of postoperative complications between the two groups

Group	CLG (n = 34)	SDLG (n = 45)	χ^2	*P*
The number of complications	16	9	6.0592	0.0138
Number of complications were not present	19	36		
Complication rate	47.06%	20%		

Note: Complication rate is expressed as a percentage of the total number of patients in each group. *P*-values are based on chi-squared tests.

Table 4. The 1-year and 3-year survival rates of the two groups were compared

Group	CLG (n = 34)	SDLG (n = 45)	χ^2	*P*
1-year post-treatment survivor count	24	40	4.2168	0.0400
1-year post-treatment mortality count	10	5		
1-year survival rate	70.59%	88.89%		
3-year post-treatment survivor count	21	37	4.1531	0.0416
3-year post-treatment mortality count	13	8		
3-year survival rate	61.76%	82.22%		

Note: The survival rate was expressed as a percentage of the total number of patients in each group. *P* value was based on chi-square test.

significantly lower overall complication incidence versus CLG ($P < 0.05$) (**Table 3**).

Longitudinal survival analysis

The SDLG demonstrated superior survival metrics, with 1- and 3-year survival rates of 88.89% (40/45) and 82.22% (37/45), respectively, significantly exceeding CLG outcomes of 70.59% (24/34) and 61.76% (21/34) (1-year: χ^2 = 4.2168, P = 0.0400; 3-year: χ^2 = 4.1531, P = 0.0416) (**Table 4**). Log-rank testing corroborated enhanced survival trajectories in the SDLG (**Figure 2**), with hazard ratio analysis revealing a 60% mortality risk reduction (HR = 0.40; 95% CI: 0.17-0.97; P = 0.0430), substantiating the prognostic benefit of suspension device-assisted 3D laparoscopic hepatectomy.

Discussion

Globally, hepatocellular carcinoma ranks among the most prevalent and lethal malignancies [28, 29]. Therapeutic modalities for hepatic neoplasms encompass surgical resection, transplantation, ablative therapies, and transarterial chemoembolization, with anatomical hepatectomy remaining the gold-standard intervention [30, 31]. Evolutionary advancements in surgical methodologies over the past three decades - particularly preoperative volumetric assessment of future liver remnants - have substantially enhanced perioperative safety profiles [32]. Contemporary surgical practice has witnessed expanding applications of minimally invasive techniques in hepatic oncology. Retrospective cohort analyses iden-

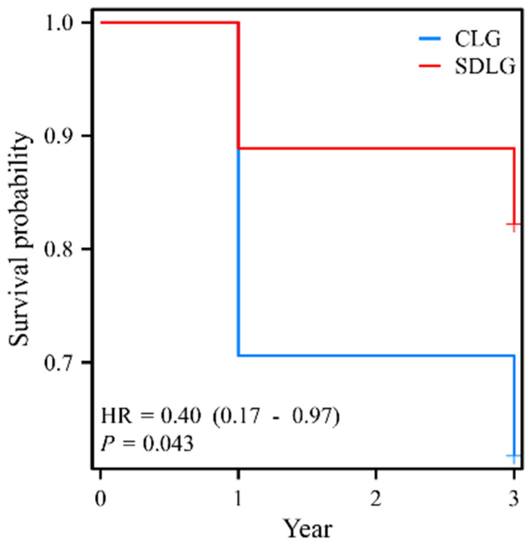

Figure 2. Comparison of survival curves between the SDLG and CLG. Note: The red line represents the SDLG, and the blue line represents the CLG. HR represents the risk ratio, and CI represents the confidence interval.

tify hepatic metastases and primary hepatocellular carcinoma as predominant indications for these procedures [33, 34]. Despite the escalating global utilization of LLR, tumoral involvement of posterosuperior segments (VI, VII) and the caudate lobe, continues to present formidable technical challenges [35, 36].

The minimally invasive paradigm of LLR confers distinct clinical advantages, including attenuated postoperative pain, expedited convalescence, and reduced morbidity rates [37-39]. Compared to conventional open procedures, laparoscopic approaches mitigate iatrogenic trauma to unaffected parenchyma, diminish nosocomial infection risks, and optimize hospitalization duration [40]. A revolutionary innovation in this domain - 3D laparoscopy - has been scientifically validated to enhance operative precision, minimize procedural errors, and augment spatial cognition during complex dissections [41, 42]. The proliferating integration of stereoscopic visualization provides unparalleled intraoperative delineation of parenchymal architecture and vascular relationships [43]. Through 3D reconstruction, surgeons achieve heightened focus on patient-specific anatomical variations, enabling meticulous preoperative strategizing [43]. The hepatic parenchyma exhibits relative fragility, where insufficient retraction may compromise tumor exposure in segments VI and VII, while excessive traction risks capsular laceration and exacerbated intraoperative hemorrhage. In this study, the innovative "T"-shaped hepatic suspension apparatus was strategically positioned near the visceral interface between segments V and VI. This design synergistically enhances surgical precision through 3D visualization-guided anatomical optimization and targeted traction, thereby elevating procedural efficiency while preserving parenchymal integrity.

Compared with the CLG, the SDLG demonstrated a marked reduction in surgical time, diminished intraoperative hemorrhage, and enhanced restoration of hepatic function during the postoperative period. The pivotal mechanism lies in the suspension apparatus achieving consistent visualization via a T-shaped fixation point, circumventing the hazards of tumor compression or capsular disruption associated with traditional traction, while distributing mechanical forces to attenuate parenchymal injury - findings corroborated by the 3D technology conclusions proposed by Au et al. [44] regarding complication mitigation. Notably, this investigation further documented a statistically significant elevation in survival rates, potentially attributable to reduced micrometastatic risk. Specifically, the device optimizes tumor exposure while concurrently curtailing operative time, blood loss, and hepatic pedicle occlusion duration, thereby ameliorating postoperative complications. The divergence in hepatic retraction techniques between SDLG and CLG cohorts constitutes the critical determinant of surgical efficacy differentiation: the SDLG attains optimal visualization through the precision and stability of its suspension system, eliminating the need for assistant-mediated liver retraction and enabling seamless coordination with primary surgical maneuvers; conversely, the CLG depends on conventional traction, necessitating greater external force application and predisposing to parenchymal trauma, thereby exacerbating intraoperative bleeding and prolonging pedicle occlusion intervals.

Regarding hepatic preservation, the SDLG cohort exhibited a markedly reduced duration of hepatic pedicle occlusion compared to the CLG, implying that the suspension apparatus indirectly refines hemodynamic regulation by minimizing visual field readjustment frequency. Postoperative Child-Pugh classification demonstrated superior improvement, attributable to a synergistic interplay of dual mechanisms: uniform traction mitigates vascular compromise (as opposed to the focal stress exerted by conventional clamps), while abbreviated operative time alleviates prolonged anesthetic and pneumoperitoneum-induced perturbations in hepatic perfusion - a correlation quantitatively validated by the convalescence trajectory reported by Au et al. [44]. Notably, despite comparable postoperative recovery metrics (e.g., hospitalization duration and drainage tube removal timing) between cohorts - indicating limited direct impact of retraction methodology on convalescence - the SDLG enhanced hepatic functional restoration underscored its parenchymal-sparing superiority. Furthermore, the SDLG manifested a significantly lower complication incidence (20% vs. 47.06%), particularly in pleural effusion, ascites, and biliary leakage, stemming from the apparatus' capacity to attenuate capsular and deep parenchymal injury via precision exposure. In contrast to the 3D reconstruction-fluorescence imaging integration proposed by Ni et al. [45] (which preserves hepatic function through truncated portal occlusion), the SDLG innovates in preempting mechanical traction-associated complications, though both modalities augment surgical safety via triaxial precision. Their synergistic deployment - merging the suspension system's stable exposure with fluorescence-guided navigation - may emerge as a novel paradigm for optimizing laparoscopic liver tumor resection in safety and efficacy.

In terms of long-term survival, the 1-year and 3-year survival rates of the SDLG demonstrated statistically significant superiority over those of the CLG. The underlying mechanism may involve a multifaceted synergistic interplay: reduced intraoperative blood loss diminishes transfusion-related immunosuppressive risks, lowered complication rates inhibit tumor microenvironment formation, and 3D visualization combined with enhanced margin tension stability elevates R0 resection rates. This outcome challenges the therapeutic equivalence framework between 3D and robotic surgery proposed by Lim et al. [46], emphasizing SDLG's innovative integration of technical advancements. The survival advantage potentially originates from: 1) precision exposure and minimally invasive techniques reducing tumor dissemination risks; 2) 3D anatomical clarity enabling radical resection completeness; 3) postoperative Child-Pugh classification improvement augmenting adjuvant therapy tolerance; 4) complication reduction improving long-term prognosis via attenuated inflammatory cascades. These observations indicate that SDLG not only refines surgical execution but amplifies oncological success through multidimensional mechanisms, establishing a novel paradigm for minimally invasive management of posterior hepatic neoplasms.

While the SDLG technique has markedly enhanced laparoscopic resection of hepatic segment VI/VII neoplasms through an innovatively engineered 'T'-shaped hepatic suspension apparatus, its inherent constraints necessitate rigorous scrutiny. Foremost, the device demands exceptional surgical virtuosity, particularly in navigating intricate anatomical terrains (e.g., discernment of posterior hepatic vascular arborizations) and achieving submillimetric tumor triangulation. Optimal outcomes mandate synergistic utilization of 3D stereoscopic visualization and dynamic suspension ergonomics to circumvent iatrogenic injury to adjacent critical architectures (e.g., hepatic venous tributaries or biliary conduits). Secondly, device efficacy exhibits patient-specific variability: in cases with compromised hepatic parenchymal integrity (e.g., Child-Pugh C cirrhosis) or deep-seated tumor topology, heterogeneous traction vector distribution during suspension predisposes to capsular fissuring or parenchymal vascular disruption, thereby exacerbating hemorrhagic sequelae. Moreover, the current iteration of suspension methodology lacks procedural codification, remaining contingent upon operator-dependent heuristics, potentially undermining interventional reproducibility.

Future research must transcend current technical constraints through the following advancements: developing modular, adjustable standardized suspension instruments capable of quantifying traction forces via embedded mechanical sensors to reduce dependence on surgical expertise; integrating intraoperative image-guidance modalities (e.g., fluorescence staining or real-time ultrasonography) for dynamic visualization of critical anatomical structures during suspension exposure, thereby minimizing iatrogenic injury risks; and executing multi-center randomized controlled trials to establish safety thresholds for SDLG in cirrhosis and other high-risk cohorts. Concurrently, the biological mechanisms underlying survival benefits demand rigorous exploration through multi-omics profiling, including comparative analyses of postoperative tumor microenvironment dynamics (inflammatory factor cascades, immune cell infiltration patterns) and circulating tumor cell (CTC) kinetics between SDLG and CLG cohorts, ultimately elucidating the causal nexus between technical innovations and long-term oncological outcomes. Such multidimensional investigations will catalyze the holistic advancement of SDLG technology, spanning operative precision to biomolecular validation. While the SDLG paradigm demonstrated superior efficacy in this investigation, sustained technical refinement and large-scale clinical corroboration remain imperative to overcome extant limitations and establish universal clinical adoption.

Limitations

Although this study demonstrates the potential advantages of the novel "T"-shaped hepatic suspension device in 3D laparoscopic NAR hepatectomy, several limitations warrant consideration. The retrospective, single-center design introduces selection bias, and the exclusion of high-risk patients (e.g., those with major vascular invasion or advanced cirrhosis) may restrict the generalizability of the findings. Technically, SDLG demands advanced proficiency in 3D laparoscopic manipulation, yet its learning curve and feasibility for widespread adoption in primary hospitals remain unquantified. While the 3-year survival outcomes are promising, the absence of ≥ 5-year follow-up data and recurrence-free survival analysis precludes definitive conclusions regarding long-term efficacy. From a health economics perspective, the cost-effectiveness comparison with conventional techniques is lacking, and the dependency on 3D laparoscopy may hinder accessibility in resource-limited settings. Furthermore, potential confounding factors - such as tumor biological heterogeneity (e.g., HCC molecular subtypes) and the lack of standardized intraoperative suspension tension control - have not been thoroughly investigated. Future multicenter randomized controlled trials with extended follow-up, integration of intelligent suspension feedback systems, and biomarker validation are imperative to substantiate its clinical value.

Conclusion

The novel hepatic suspension apparatus demonstrates substantial clinical merits when applied in 3D laparoscopic NAR hepatectomy. Relative to conventional liver grasping techniques (CLG), the SDLG cohort manifested superior perioperative metrics: diminished intraoperative hemorrhage ($P < 0.05$), abbreviated hepatic inflow occlusion duration ($P < 0.05$), and reduced total complication incidence (9 vs. 16 cases, $P < 0.05$). Notably, hospitalization length, ambulation resumption timing, and postoperative flatus recovery intervals remained statistically comparable between cohorts ($P > 0.05$). Critically, the SDLG achieved enhanced posthepatectomy functional restitution, evidenced by superior Child-Pugh score evolution ($P = 0.0128$), alongside significantly elevated 1-year (88.89% vs. 70.59%, $P = 0.040$) and 3-year survival probabilities (82.22% vs. 61.76%, $P = 0.0416$). The mortality hazard ratio for SDLG patients reached 0.40 (95% CI: 0.17-0.97, $P = 0.043$), underscoring its profound survival advantage.

These evidence-based observations posit that the suspension apparatus optimizes both procedural safety and oncological efficacy in NAR resections of segments VI and VII, while maintaining parity in immediate postoperative recovery parameters. Though clinically auspicious, this technique necessitates rigorous multicenter validation and extended longitudinal surveillance to resolve technical constraints and substantiate its generalizability across heterogeneous demographic subgroups.

Acknowledgements

This study was supported by the medical science research project of Hebei province. Foundation no. (No. 20240642).

Disclosure of conflict of interest

None.

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