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ORIGINAL RESEARCH

Practical Application of ERAS Protocols in Older Adults with Hepatocellular Carcinoma Undergoing Hepatectomy: A Propensity Score Matching Study

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Introduction: This retrospective observational study aimed to evaluate the safety and efficacy of Enhanced Recovery After Surgery (ERAS) protocols in older adult patients (≥65 years) with hepatocellular carcinoma (HCC) undergoing radical hepatectomy.

Methods: In this retrospective observational study, 498 patients who underwent radical resection for HCC between January 2018 and December 2023 were included and divided into four groups: Older adult ERAS (OE Group, n=60), Younger adult ERAS (YE Group, n=148), Older adult non-ERAS (ONE Group, n=88), and Younger adult non-ERAS (YNE Group, n=202). Propensity score matching (PSM) was performed to balance baseline covariates, generating three pairwise matched cohorts: PSM-OE Group 1 vs PSM-YE Group (both n=37), PSM-OE Group 2 vs PSM-ONE Group (both n=53), and PSM-OE Group 3 vs PSM-YNE Group (both n=35). Short-term postoperative outcomes were compared across groups.

Results: Results showed that postoperative pain control was significantly superior in PSM-OE Group 1 compared to PSM-YE Group (91.9% vs 70.3% pain-free, p=0.018) and in PSM-OE Group 2 compared to PSM-ONE Group (90.6% vs 69.8% pain-free, 7.328, p=0.013), with no significant difference between PSM-OE Group 3 and PSM-YNE Group (85.7% vs 74.3%, p=0.319). PSM-OE Group 2 had significantly shorter length of hospital stays (LOS: 13.17±4.71 vs 16.68±6.42 days, p=0.002) and length of postoperative stays (LPS: 6.94±3.26 vs 9.64±5.02 days, p=0.001) than PSM-ONE Group, while PSM-OE Group 3 also showed shorter LOS (13.31 ±4.74 vs 17.34±9.75 days, p=0.031) and LPS (7.26±3.53 vs 10.49±6.58 days, p=0.013) compared to PSM-YNE Group. The complication rate was notably lower in PSM-OE Group 2 than PSM-ONE Group (χ^2=13.747, p=0.001), with no significant differences in complication rates between other matched pairs. Blood transfusion rates, average hospitalization costs, liver reserve function (assessed by PALBI score), and 30-day readmission rates (p=0.700) showed no significant differences across all matched cohorts. Multivariate regression analysis confirmed ERAS as an independent factor associated with reduced LOS (OR=1.733, p=0.038), LPS (OR=1.901, p=0.015), postoperative pain (OR=5.014, p=0.035), and complications (OR=5.235, p=0.021).

Conclusion: ERAS protocols are safe and effective in enhancing postoperative recovery for older adult patients with HCC undergoing hepatectomy, supporting their adoption as standard perioperative care for this population.

Keywords: ERAS, older adult patients, HCC, hepatectomy

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Introduction

Hepatocellular carcinoma (HCC) remains a leading cause of cancer-related mortality globally, with a particularly high prevalence in East Asia, especially in China, which comprises the majority (62.4%) of cases in Asia.[1] Surgical resection offers the best chance for long-term survival for many patients; however, the perioperative period is critical, especially in light of the growing global elderly population, which presents unique clinical challenges. It has been proven that many older adult patients may present with functional damage of vital organs, considerably malnourished, have immune function disorders or exhibit frailty.[2] Meanwhile, the incidence of perioperative complications has doubled in elderly patients, with higher mortality, especially in those with liver disease.[3,4] The incidence of HCC in older adult patients has increased,[5] and the incidence of HCC is positively associated with age, and the onset age tends to be higher in the Asian population.[1] Additionally, malnutrition, frailty and comorbidities, are more common in older patients and often needs treatment. So, it is crucial to enhance the survival and safety of older adult patients with HCC during the perioperative period.

Enhanced recovery after surgery (ERAS) is a multidisciplinary approach to the care of the surgical patient. ERAS entails some perioperative care protocols to improve postoperative effects by modifying the inflammatory and metabolic changes associated with surgery.[6] These protocols have been widely adopted in clinical surgery, especially in older adults, and could reduce perioperative morbidity, improve functional recovery, and enhance postoperative outcomes.[7–9] In 2008, ERAS was first introduced for liver resection.[10] From then on, many studies had reported the clinical safety and efficacy of ERAS in the surgery of HCC patients for achieving rapid postoperative recovery, shortening the length of hospital stays (LOS), and reducing hospital costs.[11–14]

However, to date, no specific international clinical practice guidelines for ERAS in hepatectomy have been established, with the exception of the Chinese Expert Consensus on Enhanced Recovery After Hepatectomy (2017 Version).[15] Even within this Chinese consensus, detailed recommendations tailored to patients with HCC—a population requiring distinct perioperative management due to underlying liver dysfunction and oncologic burden—remain notably absent.

Further gaps persist in the current literature: data directly comparing ERAS effectiveness between older adult and younger adult patients with HCC are extremely limited. This research deficit is clinically meaningful, as older adults often exhibit age-related physiological changes (eg, increased frailty, and higher comorbidity burdens) that may alter their response to ERAS interventions compared to younger counterparts. Such differences suggest that a "one-size-fits-all" ERAS approach may not optimize surgical outcomes for older patients, highlighting the need for age-specific protocol refinement.

Addressing this gap is critical to advancing perioperative care for older adults with HCC—a vulnerable yet growing population. Comparative studies evaluating ERAS efficacy across age groups are therefore essential to elucidate how age modulates ERAS-related outcomes and to inform the development of tailored strategies. Against this backdrop, the primary objective of this study was to evaluate the feasibility and safety of ERAS protocols in older adult patients with HCC undergoing hepatectomy. Specifically, we compared perioperative outcomes of older adults managed with ERAS to three reference groups: older adults managed with conventional care (non-ERAS), younger adults managed with ERAS, and younger adults managed with conventional care.

Materials and Methods

Patients Enrollment

This is a single-center retrospective observational study conducted at the Department of Hepatobiliary Surgery, Sichuan Provincial People's Hospital, spanning January 2018 to December 2023. Patients were included in this study if they met all the following criteria: Pathologically confirmed diagnosis of HCC; Underwent curative-intent surgical resection at the Department; Surgery was performed between January 2018 and December 2023. The exclusion criteria were as follows: Underwent Associating Liver Partition and Portal Vein Ligation for Staged Hepatectomy (ALPPS); Received only liver biopsy combined with local ablation therapy; Underwent surgery for metastatic lesions (eg, retroperitoneal masses) rather than primary HCC; Underwent simultaneous additional procedures, including splenectomy or portal vein embolization; Incomplete clinical or follow-up data (to ensure the reliability of outcome analysis).

Starting January 1, 2022, a standardized ERAS protocol was implemented for patients undergoing HCC resection at our institution. This protocol was developed in accordance with the Chinese Expert Consensus on Enhanced Recovery After Hepatectomy (2017 Version).[15] All consecutive patients who underwent surgery on or after this date were managed in strict adherence to the ERAS guidelines, while historical controls (patients who underwent surgery before January 1, 2022) received conventional perioperative care.

Patient stratification into four study groups was based on two criteria: admission date (to differentiate ERAS vs non-ERAS management periods) and age (to distinguish older vs younger adults). Consistent with the World Health Organization (WHO) definition, "older adults" were defined as individuals aged ≥65 years, and "younger adults" as those aged <65 years. The four study groups were as follows:

1. Older adult ERAS group (OE group): Patients aged ≥65 years admitted on or after January 1, 2022 (managed with ERAS);
2. Younger adult ERAS group (YE group): Patients aged <65 years admitted on or after January 1, 2022 (managed with ERAS);
3. Older adult non-ERAS group (ONE group): Patients aged ≥65 years admitted before January 1, 2022 (managed with conventional care);
4. Younger adult non-ERAS group (YNE group): Patients aged <65 years admitted before January 1, 2022 (managed with conventional care).

This study was conducted in compliance with the principles of the Declaration of Helsinki and was approved by the Medical Ethics Committee of Sichuan Provincial People's Hospital, School of Medicine, University of Electronic Science and Technology of China (Ethics Review Resolution No. 192, 2023). Formal written informed consent was waived by the Ethics Committee for the following reasons: (1) the research posed no more than minimal risk to participants; (2) the waiver did not compromise the rights or welfare of participants; and (3) all data analyzed were retrospective and fully anonymized to protect patient privacy.

The Definition of Clinical Characteristics

For liver function assessment, we have replaced the previously common Child-Pugh score with the more objective Platelet-Albumin-Bilirubin (PALBI) score. By calculating the PALBI scores before surgery and prior to discharge, we can compare the overall changes in liver function scores across different groups, as well as the individual changes in liver function scores for each patient. The PALBI score is calculated using the following formula:[16]

$\text{PALBI} = (2.02 \times \text{Log}_{10}\ \text{bilirubin}) + [-0.37 \times (\text{Log}_{10}\ \text{bilirubin})^2] + (-0.04 \times \text{albumin}) + (-3.48 \times \text{Log}_{10}\ \text{platelets}) + [1.01\ (\text{Log}_{10}\ \text{platelets})^2]$

where bilirubin is in μmol/L and albumin in g/L, and platelet count in 1000/μL. The PALBI is categorized into three levels: PALBI Grade 1 (score ≤ −2.53), PALBI Grade 2 (score > −2.53 and ≤ −2.09), and PALBI Grade 3 (score > −2.09).

Additionally, the Body Mass Index (BMI) is categorized as follows: Underweight = <18.5; Normal weight = 18.5–24.9; Overweight = 25–29.9; Obesity = BMI of 30 or greater.

Liver resection methods were classified based on the extent of the liver removed:[17] Major Hepatectomy(MJH) involves the removal of more than two segments of the liver, while Minor Hepatectomy (MIH) includes the removal of two segments or fewer, including local tumor resection.

The methods of hepatic inflow occlusion were categorized into three types based on the extent of vascular occlusion: total hepatic inflow occlusion (Pringle maneuver), hemihepatic inflow occlusion (HIO), and others (with unspecified or atypical occlusion patterns).

HCC staging was performed according to the BCLC classification, which ranges from stage 0 to C (four stages).

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Pain assessment was conducted on the third postoperative day using a visual analog scale,[18] categorizing pain into four levels: No pain (0), Mild pain (1–3) = 1, Moderate pain (4–6) = 2, Severe pain (7–10) = 3.

Postoperative complications were graded according to the Clavien-Dindo classification,[19] with a three-tier grading framework established for standardized outcome assessment: Grade 0 (No Complication) denoted the absence of any postoperative adverse events; Grade 1 included mild complications corresponding to Clavien-Dindo grades ≤3; and Grade 2 represented acute severe complications equivalent to Clavien-Dindo grades >3.

Specific Clinical Management Protocols for Different Patients

In the patients without ERAS protocols, standard preoperative assessments, surgical procedures, and perioperative management were followed. In contrast, in addition to the standard procedures, ERAS protocols were implemented for HCC patients after 2022, which included preoperative education, respiratory function training, three-dimensional imaging of liver tumors before surgery, controlled fluid administration during surgery, early removal of the gastric tube and urinary catheter postoperatively, mechanical massage for both lower legs, and encouragement for early mobilization and liquid diet. (Table 1)

Data Collection and Study Endpoints

Data were collected from electronic medical records, including patient demographics, comorbidities, intraoperative details, and postoperative outcomes. Given the subjective nature of metrics such as the timing of drainage tube removal, initiation of oral intake, and time to flatus, we focused on more objective outcomes to ensure the reliability of the

Table 1 Clinical Management Protocols for ERAS Patients

Preoperative management	ERAS programs are introduced during preoperative education. Smoke cessation; Alcohol cessation. NRS-2002 evaluation and Caprini venous thrombosis. Routine respiratory function exercise. Patients should fast for 6 hours and avoid drinking for 2 hours before surgery. Administer 250 mL of an oral carbohydrate solution two hours prior to surgery; for diabetic patients, replace this with an equivalent amount of normal saline. Child-Pugh grading and ICG liver function evaluation Accurate liver resection planning under three-dimensional reconstruction and ERAS management risk evaluation and control 400mg Celebrex was taken orally at night before operation. No preoperative bowel preparation.
Intraoperative management	Routine usage of prophylactic antibiotics. Multi-mode individualized anesthesia program. Low CVP technique [CVP < 5 mmHg, systolic blood pressure > 90 mmHg] + perioperative goal directed fluid therapy. Individualized liver blood flow control technique and delicate liver parenchyma dissection technique. Prevent hypothermia by maintaining body temperature above 36.0°C during the operation. Employ preventive analgesia with incision injection of long-acting local anesthetics.
Postoperative management	Use selective indwelling drainage tubes, avoid routine nasogastric tubes, and ensure early removal of catheters. Implement a comprehensive, quantitative, and dynamic evaluation alongside preventive multimodal analgesic management, utilizing a routine analgesic pump for two days, supplemented by opioids and non-steroidal anti-inflammatory drugs. Administer nebulization in addition to routine intravenous therapy, along with physical expectoration training. Limit fluid intake to less than 20 mL for the first six hours post-operation, and begin a liquid or semi-liquid diet one day after surgery, gradually advancing to a normal diet. Mobilization should start one day post-operation, with daily activity goals established and activity levels increased progressively. Remove urinary catheters one day post-operation, and withdraw other drainage tubes as soon as the drainage conditions permit. Based on the patient's rate of recovery, arrange for discharge at the earliest opportunity and schedule a follow-up visit two weeks post operation.

Abbreviations: ERAS, Enhanced Recovery After Surgery; ICG, indocyanine green; CVP, central venous pressure.

analysis. Additionally, to minimize confounding from immediate postoperative factors (eg, residual anesthesia effects or conventional analgesic use for breakthrough pain), pain was assessed on postoperative day 3 when such influences are deemed negligible. Then, the pain score on postoperative day 3 and the length of postoperative stays (LPS) were selected as the primary endpoints. The secondary endpoints included recovery of liver function, postoperative complications, LOS, readmission rate, and hospitalization costs.

Statistical Analysis

Continuous variables were expressed as mean ± standard deviation if normally distributed (verified via Shapiro–Wilk test) or median (range) if non-normally distributed, while categorical variables were presented as number (percentage, n %). Non-normally distributed continuous variables and normally distributed continuous variables were compared using the Mann–Whitney *U*-test and independent samples *t*-test for pairwise comparisons, respectively, with one-way analysis of variance (ANOVA) or Kruskal–Wallis *H*-test for overall comparisons across the four study groups (OE Group, YE Group, ONE Group, YNE Group), while categorical variables were compared using the χ^2-test or Fisher's exact test. To mitigate the effects of baseline imbalances between the four groups, 1:1 nearest neighbor propensity score matching (PSM) was performed separately based on stratification by age and ERAS application with a caliper width of 0.2 × standard deviation of the logit of the propensity score. Propensity scores were estimated using a logistic regression model incorporating relevant preoperative covariates, including gender, HBV/HCV infection, ultrasonic cardiogram results, and so on. Covariate balance before and after PSM was assessed using standardized mean differences (SMDs), with values < 0.2 indicating adequate balance.[20] Potential risk factors for postoperative outcomes identified through univariate analysis ($p < 0.10$) were subsequently assessed through multivariate analysis using logistic regression. The analysis was restricted to patients with complete data for all variables included in that particular model or comparison. The sample size for each analysis is explicitly reported in the respective table footnotes. All tests were two-tailed, and $p < 0.05$ was considered statistically significant. Statistical analyses were conducted using IBM SPSS Statistics Version 27 (IBM Corporation, Armonk, NY, USA).

Results

Demographic and Baseline Characteristics

Initially, 515 patients with pathologically confirmed HCC were screened for eligibility. Per the predefined exclusion criteria, 17 patients were excluded: 7 who underwent only needle biopsy (without surgical resection), 7 who received ALPPS, and 3 who required reoperation for postoperative retroperitoneal metastasis. After these exclusions, 498 patients were included in the final analysis and were allocated to four groups as follows: the OE group (n=60, 12.0%), the YE group (n=148, 29.7%), the ONE group (n=88, 17.7%), and the YNE group (n=202, 40.6%). The implementation rate of ERAS items was > 95% in the ERAS groups (OE and YE), verified by reviewing medical records (preoperative education, respiratory training, early mobilization, etc. were documented in all ERAS patients). Patients in the non-ERAS groups (ONE and YNE) received some individual elements of perioperative care that overlap with ERAS principles (such as postoperative analgesia, regular turning, and early mobilization). However, they were not managed under a structured, multimodal ERAS protocol. Post-hoc power analysis showed the sample size was sufficient to detect differences in primary outcomes (pain score and postoperative stay) with a power of 85% (α=0.05).

Among them, 85 (17.1%) were female and 413 (82.9%) were male, with a mean age of 57.9 ± 11.7 years. The average LOS was 14.6 ± 6.3 days, including a postoperative stay of 8.4 ± 4.8 days. The average hospitalization costs were 68,213.66 ± 36,818.65 RMB. No cases of deep vein thrombosis occurred within 30 days post-surgery. However, there were 8 readmissions within 30 days after discharge. Of these, 1 patient from the OE group was readmitted due to multiple lesions and required additional TACE treatment. In the YE group, 1 patient was readmitted for the drainage of postoperative perihepatic fluid. In the ONE group, 2 patients were readmitted: one for a wound infection that required further intervention, and the other for postoperative bleeding that necessitated TACE for hemostasis. Lastly, in the YNE group, 4 patients were readmitted, including one for postoperative bleeding requiring TACE, one for drainage of postoperative abdominal fluid, and two for additional TACE treatment. The difference in readmission rates was not statistically significant. ($\chi2$=1.423, P=0.700). As shown in Tables 2–4, PSM was applied to balance baseline covariates, yielding three pairwise matched cohorts: PSM-OE group 1 vs PSM-YE group (both n=37); PSM-OE Group 2 vs PSM-ONE Group (both n=53); and PSM-OE Group 3 vs PSM-YNE (both n=35). (Tables 2–4)

After PSM, no patients were excluded from the analysis. Covariate balance before and after PSM was assessed using SMDs, nearly all SMD values <0.2 after matching except Age, indicating adequate balance (detailed SMD data are provided in Tables 2–4). Specifically, the distribution of pre-discharge PALBI grades (Grade 1: ≤2.53; Grade 2: >2.53; Grade 3) showed no intergroup differences in the key pairwise comparisons. For instance, in the age-stratified cohort (PSM-OE Group 1, n=24; PSM-YE Group, n=22), the Fisher-Freeman-Halton exact test confirmed no significant difference in PALBI grade distribution between the two groups (P=0.425). This indicated that the confounding effects of baseline factors were effectively minimized, ensuring the comparability of postoperative outcomes across groups.

Comparison of Postoperative Indicators in Different Groups (Table 5)

Postoperative Pain

A notably higher proportion of patients reported no pain in the PSM-OE Group 1 and 2 than in the PSM-YE group (91.9% vs 70.3%; χ^2=5.638, P=0.018) and PSM-ONE group (91.9% vs 69.8%; χ^2=7.328, P=0.013), respectively. By contrast, no significant difference in pain distribution was observed between the PSM-OE Group 3 and PSM-YNE groups (85.7% vs 74.3%; χ^2=2.260, P=0.319).

Lengths of Hospital and Postoperative Stays

Total and postoperative hospital stays were comparable between PSM-OE Group 1 and PSM-YE Group (total: 13.43 ±5.56 vs 13.16±6.05 days, t=0.20, P=0.842; postoperative: 7.62±4.16 vs 7.32±5.29 days, t=0.27, P=0.789). In contrast, PSM-OE Groups 2 and 3 had significantly shorter total and postoperative stays than PSM-ONE (total: 13.17±4.71 vs 16.68±6.42 days, t=−3.21, P=0.002; postoperative: 6.94±3.26 vs 9.64±5.02 days, t=−3.28, P=0.001) and PSM-YNE Groups (total: 13.31±4.74 vs 17.34±9.75 days, t=−2.20, P=0.031; postoperative: 7.26±3.53 vs 10.49±6.58 days, t=−2.56, P=0.013), respectively.

Blood Transfusion Rate

No significant differences in blood transfusion rates were detected across all three pairwise comparisons (all P>0.05), suggesting that ERAS implementation did not increase the risk of perioperative blood transfusion in elderly hepatectomy patients.

Liver Reserve Function (PALBI Grade)

The distribution of pre-discharge PALBI grades and postoperative changes in PALBI grades showed no statistically significant differences among any matched pairs (all P>0.05). This finding indicated that ERAS management did not compromise postoperative liver function recovery in elderly patients.

Postoperative Complications

The incidence of postoperative complications was similar between the PSM-OE group 1 and PSM-YE groups (P=1.000) and between the PSM-OE group 3 and PSM-YNE groups (P=0.266). However, the PSM-OE group 2 had a substantially lower complication rate than the PSM-ONE group (χ^2=13.75, P=0.001), highlighting the protective effect of ERAS against postoperative adverse events in elderly patients.

Average Hospitalization Costs

Average hospitalization costs were comparable across all matched cohorts (all P>0.05), demonstrating that ERAS implementation did not add to the economic burden of hepatectomy in elderly patients.

Results of Multivariate Regression Analysis

To address potential confounding factors, multivariate regression analyses were performed to identify specific factors that significantly influence various outcome measures overall. Subsequently, these findings were compared with previous results to assess consistency.

Table 2 Baseline Characteristics of Patients Before and After Propensity Score Matching (OE Group vs YE Group)

Baseline Variable		Before PSM					After PSM				
		OE Group (n=60, %)	YE Group (n=148,%)	χ^2/t	P value	SMD Value	PSM-OE Group 1 (n=37, %)	PSM-YE Group (n=37, %)	χ^2/t	P value	SMD Value
Age (yrs)		71.4±5.4	52.2±9.6	18.304	0.000	2.230	71.65±5.33	55.18±5.87	12.641	0.000	2.939
Gender	Female	14(23.3)	25(16.9)	1.163	0.281	−0.164	8(21.6)	4(10.8)	1.591	0.207	0.260
	Male	46(76.7)	123(83.1)	–	–	–	29(78.4)	33(89.2)	–	–	–
HBV/HCV Infection	No	16(26.7)	19(12.8)	5.834	0.016	−0.372	11(29.7)	8(21.6)	0.637	0.425	0.190
	Yes	44(73.3)	129(87.2)	–	–	–	26(70.3)	29(78.4)	–	–	–
Ultrasonic Cardiogram	No	35(58.3)	128(86.5)	61.429	0.000	0.685	27(73.0)	26(70.3)	0.066	0.797	0.060
	Yes	25(41.7)	20(13.5)	–	–	–	10(27.0)	11(29.7)	–	–	–
History of Other Tumors	No	57(95.0)	144(97.3)	0.166	0.683	0.127	35(94.6)	36(97.3)	0.345	0.557	0.100
	Yes	3(5.0)	4(2.7)	–	–	–	2(5.4)	1(2.7)	–	–	–
Diabetes Mellitus	No	45(75.0)	138(93.2)	13.437	0.000	0.559	30(81.1)	29(78.4)	0.084	0.772	0.070
	Yes	15(25.0)	10(6.8)	–	–	–	7(18.9)	8(21.6)	–	–	–
Anemia	No	35(58.3)	122(82.4)	13.397	0.000	0.560	25(67.6)	28(75.7)	0.598	0.439	0.180
	Yes	25(41.7)	26(17.6)	–	–	–	12(32.4)	9(24.3)	–	–	–
PALBI Score*	Grade 1	19(31.7)	73(50.3)	5.970	0.051	0.374	12(32.4)	15(40.5)	1.377	0.502	0.170
	Grade 2	26(43.3)	49(33.8)	–	–	–	19(51.4)	14(37.8)	–	–	–
	Grade 3	15(25.0)	23(15.9)	–	–	–	6(16.2)	8(21.6)	–	–	–
BMI Grade	Underweight	9(15.0)	8(5.4)	0.050	0.823	−0.149	4(10.8)	1(2.7)	2.628	0.453	0.220
	Normal	36(60.0)	93(62.8)	–	–	–	24(64.9)	23(62.2)	–	–	–
	Overweight	13(21.7)	43(29.1)	–	–	–	8(21.6)	11(29.7)	–	–	–
	Obesity	2(3.3)	4(2.7)	–	–	–	1(2.7)	2(5.4)	–	–	–
Smoking History	No	35(58.3)	92(62.2)	0.263	0.608	0.080	21(56.8)	18(48.6)	0.488	0.485	0.160
	Yes	25(41.7)	56(37.8)	–	–	–	16(43.2)	19(51.4)	–	–	–

(*Continued*)

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Table 2 (Continued).

Baseline Variable		Before PSM					After PSM				
		OE Group (n=60, %)	YE Group (n=148,%)	χ^2/t	P value	SMD Value	PSM-OE Group I (n=37, %)	PSM-YE Group (n=37, %)	χ^2/t	P value	SMD Value
Alcohol Addiction	No	42(70.0)	114(77.0)	0.958	0.328	0.162	26(70.3)	28(75.7)	0.274	0.601	0.120
	Yes	18(30.0)	34(23.0)	–	–	–	11(29.7)	9(24.3)	–	–	–
Liver Cirrhosis*	No	24(40.0)	67(45.9)	0.598	0.439	0.119	20(54.1)	19(51.4)	0.054	0.816	0.050
	Yes	36(60.0)	79(54.1)	–	–	–	17(45.9)	18(48.6)	–	–	–
Previous upper abdominal surgery	No	50(83.3)	125(84.5)	0.041	0.840	0.033	30(81.1)	31(83.8)	0.093	0.760	0.030
	Yes	10(16.7)	23(15.5)	–	–	–	7(18.9)	6(16.2)	–	–	–
Portal Blocking Method	Pringle	52(86.7)	121(81.8)	1.477	0.688	0.131	37(100.0)	36(97.3)	1.014	0.314	0.140
	HIO	3(5.0)	15(10.1)	–	–	–	0(0.0)	1(2.7)	–	–	–
	Others	5(8.3)	12(8.1)	–	–	–	0(0.0)	0(0.0)	–	–	–
Portal Blocking Time (min)*		43.9±16.8	52.2±9.6	0.319	0.750	−0.686	45.54±15.89	44.59±17.13	0.246	0.806	0.057
Hepatectomy Method	MJH	21(35.0)	67(45.3)	1.845	0.174	0.208	23(62.2)	21(56.8)	0.224	0.636	0.110
	MIH	39(65.0)	81(54.7)	–	–	–	14(37.8)	16(43.2)	–	–	–
Concurrent Ablation	Yes	5(8.3)	14(9.5)	0.065	0.798	−0.042	5(13.5)	2(5.4)	1.420	0.233	0.290
	No	55(91.7)	134(90.5)	–	–	–	32(86.5)	35(94.6)	–	–	–
Laparoscopic Hepatectomy	No	31(51.7)	72(48.6)	0.156	0.693	−0.062	16(43.2)	19(51.4)	0.488	0.485	0.160
	Yes	29(48.3)	76(51.4)	–	–	–	21(56.8)	18(48.6)	–	–	–
BCLC Stage	Stage 0	2(3.3)	8(5.4)	3.670	0.470	−0.067	2(5.4)	1(2.7)	1.751	0.626	0.090
	Stage A	47(78.3)	109(73.6)	–	–	–	28(75.7)	29(78.4)	–	–	–
	Stage B	9(15.0)	18(12.2)	–	–	–	6(16.2)	4(10.8)	–	–	–
	Stage C	2(3.3)	13(8.8)	–	–	–	1(2.7)	3(8.1)	–	–	–

Notes: *Only included the cases with available statistical values. Values of χ^2 and t represent comparisons between the Older adult Enhanced Recovery After Surgery (OE) Group and the Younger adult Enhanced Recovery After Surgery (YE) Group before and after PSM, respectively. SMD calculated methods: Binary variable; SMD calculated by weighted pooled rate method; Nominal variable; SMD calculated by core subgroup method; Continuous variable; SMD calculated by pooled SD method; Ordinal variable; SMD calculated by core subgroup method.

Abbreviations: PSM, Propensity Score Matching; BMI, Body Mass Index; HIO, Hemihepatic Inflow Occlusion; MJH, Major Hepatectomy; MIH, Minor Hepatectomy.

Table 3 Baseline Characteristics of Patients Before and After Propensity Score Matching (OE Group vs ONE Group)

Baseline Variable		**Before PSM**					**After PSM**				
		OE Group (n=60, %)	**ONE Group (n=88,%)**	**χ^2/t**	**P value**	**SMD Value**	**PSM-OE Group 2 (n=53, %)**	**PSM-ONE Group (n=53, %)**	**χ^2/t**	**P value**	**SMD Value**
Age (yrs)		71.4±5.4	71.0±4.2	0.483	0.630	0.085	71.71±5.59	70.99±4.44	0.731	0.466	0.142
Gender	Female	14(23.3)	16(18.2)	0.586	0.444	−0.128	14(26.4)	10(18.9)	0.862	0.353	0.179
	Male	46(76.7)	72(81.8)	-	-	-	39(73.6)	43(81.1)	-	-	-
HBV/HCV Infection	No	16(26.7)	21(24.1)	0.121	0.728	0.058	15(28.3)	11(21.2)	0.720	0.396	0.178
	Yes	44(73.3)	66(75.9)	–	–	–	38(71.7)	41(78.8)	–	–	–
Ultrasonic Cardiogram	No	35(58.3)	54(61.4)	0.137	0.712	0.062	30(56.6)	29(54.7)	0.038	0.845	0.039
	Yes	25(41.7)	34(38.6)	-	-	-	23(43.4)	24(45.3)	-	-	-
History of Other Tumors	No	57(95.0)	87(98.9)	0.822	0.364	0.181	50(94.3)	52(98.1)	1.039	0.308	0.200
	Yes	3(5.0)	1(1.1)	–	–	–	3(5.7)	1(1.9)	–	–	–
Diabetes Mellitus	No	45(75.0)	68(77.3)	0.102	0.749	0.053	41(77.4)	41(77.4)	0.000	1.000	0.000
	Yes	15(25.0)	20(22.7)	-	-	-	12(22.6)	12(22.6)	-	-	-
Anemia	No	35(58.3)	64(72.7)	3.338	0.068	0.306	33(62.3)	33(62.3)	0.000	1.000	0.000
	Yes	25(41.7)	24(27.3)	–	–	–	20(37.7)	20(37.7)	–	–	–
PALBI Score*	Grade 1	19(31.7)	37(42.0)	2.988	0.224	0.220	18(34.0)	16(30.2)	0.201	0.904	0.082
	Grade 2	26(43.3)	38(43.2)	-	-	-	25(47.2)	26(49.1)	-	-	-
	Grade 3	15(25.0)	13(14.8)	-	-	-	10(18.9)	11(20.8)	-	-	-
BMI Grade	Underweight	9(15.0)	8(9.1)	0.302	0.583	0.185	7(13.2)	6(11.3)	0.743	0.863	0.118
	Normal	36(60.0)	52(59.1)	–	–	–	23(43.4)	27(51.0)	–	–	–
	Overweight	13(21.7)	24(27.3)	–	–	–	17(32.1)	16(30.2)	–	–	–
	Obesity	2(3.3)	4(4.5)	–	–	–	6(11.3)	4(7.5)	–	–	–
Smoking History	No	35(58.3)	59(67.0)	1.168	0.280	0.181	35(66.0)	34(64.2)	0.042	0.839	0.038
	Yes	25(41.7)	29(33.0)	–	–	–	18(34.0)	19(35.8)	–	–	–

(*Continued*)

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Table 3 (Continued).

Baseline Variable		Before PSM					After PSM				
		OE Group (n=60, %)	ONE Group (n=88,%)	χ^2/t	P value	SMD Value	PSM-OE Group 2 (n=53, %)	PSM-ONE Group (n=53, %)	χ^2/t	P value	SMD Value
Alcohol Addiction	No	42(70.0)	52(59.1)	1.832	0.176	0.227	36(67.9)	38(71.7)	0.179	0.672	0.081
	Yes	18(30.0)	36(40.9)	–	–	–	17(32.1)	15(28.3)	–	–	–
Liver Cirrhosis*	No	24(40.0)	34(38.6)	0.028	0.867	0.028	33(62.3)	36(67.9)	0.374	0.541	0.117
	Yes	36(60.0)	54(61.4)	–	–	–	20(37.7)	17(32.1)	–	–	–
Previous upper abdominal surgery	No	50(83.3)	81(92.0)	2.663	0.103	0.273	44(83.0)	47(88.7)	0.699	0.403	0.159
	Yes	10(16.7)	7(8.0)	–	–	–	9(17.0)	6(11.3)	–	–	–
Portal Blocking Method	Pringle	52(86.7)	74(84.1)	1.601	0.449	0.073	45(84.9)	47(88.7)	0.329	0.566	0.116
	HIO	3(5.0)	9(10.2)	–	–	–	0(0.0)	0(0.0)	–	–	–
	Others	5(8.3)	5(5.7)	–	–	–	8(15.1)	6(11.3)	–	–	–
Portal Blocking Time (min)*		43.9±16.8	44.3±16.8	−0.126	0.900	0.023	43.11±15.79	46.74±17.49	−1.038	0.302	0.218
Hepatectomy Method	MJH	21(35.0)	34(38.6)	0.202	0.653	0.075	18(34.0)	22(41.5)	0.642	0.423	0.157
	MIH	39(65.0)	54(61.4)	–	–	–	35(66.0)	31(58.5)	–	–	–
Concurrent Ablation	Yes	5(8.3)	10(11.4)	0.360	0.549	0.100	4(7.5)	4(7.5)	0.000	1.000	0.000
	No	55(91.7)	78(88.6)	–	–	–	49(92.5)	49(92.5)	–	–	–
Laparoscopic Hepatectomy	No	31(51.7)	50(56.8)	0.382	0.536	0.104	28(52.8)	28(52.8)	0.000	1.000	0.000
	Yes	29(48.3)	38(43.2)	–	–	–	25(47.2)	25(47.2)	–	–	–
BCLC Stage	Stage 0	2(3.3)	2(2.3)	2.380	0.497	0.210	2(3.8)	2(3.8)	2.983	0.394	0.046
	Stage A	47(78.3)	61(69.3)	–	–	–	40(75.5)	39(73.6)	–	–	–
	Stage B	9(15.0)	18(20.5)	–	–	–	9(16.9)	8(15.1)	–	–	–
	Stage C	2(3.3)	7(8.0)	–	–	–	2(3.8)	4(7.5)	–	–	–

Notes: *Only included the cases with available statistical values. Values of χ^2 and t represent comparisons between the Older adult Enhanced Recovery After Surgery (OE) Group and the Older adult non-Enhanced Recovery After Surgery (ONE) Group before and after PSM, respectively. SMD calculated methods: Binary variable; SMD calculated by weighted pooled rate method; Nominal variable; SMD calculated by core subgroup method; Continuous variable; SMD calculated by pooled SD method; Ordinal variable; SMD calculated by core subgroup method.

Abbreviations: PSM, Propensity Score Matching; BMI, Body Mass Index; HIO, Hemihepatic Inflow Occlusion; MJH, Major Hepatectomy; MIH, Minor Hepatectomy.

Table 4 Baseline Characteristics of Patients Before and After Propensity Score Matching (OE Group vs YNE Group)

Baseline Variable		**Before PSM**					**After PSM**				
		OE Group (n=60, %)	**YNE Group (n=202,%)**	χ^2/t	**P value**	**SMD Value**	**PSM-OE Group 3 (n=35, %)**	**PSM-YNE Group (n=35, %)**	χ^2/t	**P value**	**SMD Value**
Age (yrs)		71.4±5.4	52.3±8.4	20.895	0.000	2.250	71.22±5.13	52.02±9.48	18.762	<0.001	2.520
Gender	Female	14(23.3)	30(14.9)	2.392	0.123	0.200	7(20.0)	10(28.6)	0.699	0.403	0.186
	Male	46(76.7)	172(85.1)	-	-	-	28(80.0)	25(71.4)	-	-	-
HBV/HCV Infection	No	16(26.7)	22(10.9)	9.284	0.002	0.450	6(17.1)	4(11.4)	0.467	0.495	−0.158
	Yes	44(73.3)	180(89.1)	–	–	–	29(82.9)	31(88.6)	–	–	–
Ultrasonic Cardiogram	No	35(58.3)	182(90.1)	151.667	0.000	0.880	25(71.4)	25(71.4)	0.000	1.000	0.000
	Yes	25(41.7)	20(9.9)	-	-	-	10(28.6)	10(28.6)	-	-	-
History of Other Tumors	No	57(95.0)	197(97.5)	0.996	0.318	0.130	33(94.3)	34(97.1)	0.348	0.555	0.120
	Yes	3(5.0)	5(2.5)	–	–	–	2(5.7)	1(2.9)	–	–	–
Diabetes Mellitus	No	45(75.0)	181(89.6)	8.324	0.004	0.360	30(85.7)	28(80.0)	0.402	0.526	−0.154
	Yes	15(25.0)	21(10.4)	-	-	-	5(14.3)	7(20.0)	-	-	-
Anemia	No	35(58.3)	163(80.7)	12.528	0.000	0.510	23(65.7)	24(68.6)	0.065	0.799	0.063
	Yes	25(41.7)	39(19.3)	–	–	–	12(34.3)	11(31.4)	–	–	–
PALBI Score*	Grade 1	19(31.7)	85(42.9)	2.555	0.279	0.230	9(25.7)	12(34.3)	0.686	0.710	0.192
	Grade 2	26(43.3)	75(37.9)	-	-	-	19(54.3)	16(45.7)	-	-	-
	Grade 3	15(25.0)	38(19.2)	-	-	-	7(20.0)	7(20.0)	-	-	-
BMI Grade	Underweight	9(15.0)	10(5.0)	7.134	0.068	0.290	6(17.1)	2(5.7)	3.581	0.310	0.000
	Normal	36(60.0)	130(64.4)	–	–	–	19(54.3)	24(68.6)	–	–	–
	Overweight	13(21.7)	55(27.2)	–	–	–	9(25.7)	9(25.7)	–	–	–
	Obesity	2(3.3)	7(3.5)	–	–	–	1(2.9)	0(0.0)	–	–	–
Smoking History	No	35(58.3)	124(61.4)	0.181	0.671	0.070	21(60.0)	23(65.7)	0.245	0.621	0.118
	Yes	25(41.7)	78(38.6)	-	-	-	14(40.0)	12(34.3)	-	-	-

(*Continued*)

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Table 4 (Continued).

Baseline Variable		**Before PSM**					**After PSM**				
		OE Group (n=60, %)	**YNE Group (n=202,%)**	**χ^2/t**	**P value**	**SMD Value**	**PSM-OE Group 3 (n=35, %)**	**PSM-YNE Group (n=35, %)**	**χ^2/t**	**P value**	**SMD Value**
Alcohol Addiction	No	42(70.0)	141(69.8)	0.001	0.977	0.005	26(74.3)	24(68.6)	0.280	0.597	−0.122
	Yes	18(30.0)	61(30.2)	–	–	–	9(25.7)	11(31.4)	–	–	–
Liver Cirrhosis*	No	24(40.0)	70(34.7)	0.575	0.448	0.110	17(48.6)	19(54.3)	0.229	0.632	0.114
	Yes	36(60.0)	132(65.3)	–	–	–	18(51.4)	16(45.7)	–	–	–
Previous upper abdominal surgery	No	50(83.3)	182(90.1)	2.088	0.148	0.170	31(88.6)	31(88.6)	0.467	0.495	−0.158
	Yes	10(16.7)	20(9.9)	–	–	–	4(11.4)	7(17.1)	–	–	–
Portal Blocking Method	Pringle	52(86.7)	156(77.2)	2.548	0.280	0.210	34(97.1)	32(91.4)	1.061	0.303	0.252
	HIO	3(5.0)	19(9.4)	–	–	–	1(2.9)	3(8.6)	–	–	–
	Others	5(8.3)	27(13.4)	–	–	–	0(0.0)	0(0.0)	–	–	–
Portal Blocking Time (min)*		43.9±16.8	39.5±17.6	1.606	0.110	0.120	41.57±16.31	42.43±20.09	0.198	0.845	−0.047
Hepatectomy Method	MJH	21(35.0)	81(40.1)	0.506	0.477	0.100	19(54.3)	21(60.0)	0.245	0.621	−0.118
	MIH	39(65.0)	121(59.9)	–	–	–	16(45.7)	14(40.0)	–	–	–
Concurrent Ablation	Yes	5(8.3)	21(10.4)	0.220	0.639	0.070	4(11.4)	2(5.7)	0.729	0.393	0.190
	No	55(91.7)	181(89.6)	–	–	–	31(88.6)	33(94.3)	–	–	–
Laparoscopic Hepatectomy	No	31(51.7)	111(55.0)	0.201	0.654	0.070	19(54.3)	22(62.9)	0.530	0.467	0.174
	Yes	29(48.3)	91(45.0)	–	–	–	16(45.7)	13(37.1)	–	–	–
BCLC Stage	Stage 0	2(3.3)	12(5.9)	7.492	0.058	0.240	1(2.9)	6(17.1)	7.248	0.064	0.072
	Stage A	47(78.3)	126(62.4)	–	–	–	27(77.1)	18(51.4)	–	–	–
	Stage B	9(15.0)	34(16.8)	–	–	–	6(17.1)	7(20.0)	–	–	–
	Stage C	2(3.3)	30(14.9)	–	–	–	1(2.9)	4(11.4)	–	–	–

Notes:*Only included the cases with available statistical values. Values of χ^2 and t represent comparisons between the Older adult Enhanced Recovery After Surgery (OE) Group and the Younger adult non-Enhanced Recovery After Surgery (YNE) Group before and after PSM, respectively. SMD calculated methods: Binary variable; SMD calculated by weighted pooled rate method; Nominal variable; SMD calculated by core subgroup method; Continuous variable; SMD calculated by pooled SD method; Ordinal variable; SMD calculated by core subgroup method.

Abbreviations: PSM, Propensity Score Matching; BMI, Body Mass Index; HIO, Hemihepatic Inflow Occlusion; MJH, Major Hepatectomy; MIH, Minor Hepatectomy.

Table 5 Comparative Analysis of Postoperative Outcomes in the Propensity Score-Matched Cohorts Using Pairwise Testing

Outcome Variable	PSM-OE Group 1 (n=37, %)	PSM-YE Group (n=37, %)	t/ χ^2	p1	PSM-OE Group 2 (n=53, %)	PSM-ONE Group (n=53, %)	t/ χ^2	p2	PSM-OE Group 3 (n=35, %)	PSM-YNE Group (n=35, %)	t/ χ^2	P3
Postoperative Pain												
0	34(91.9)	26(70.3)	5.638	0.018	48(90.6)	37(69.8)	7.328	0.013	30(85.7)	26(74.3)	2.260	0.319
1	3(8.1)	11(29.7)			5(9.4)	15(28.3)			5(14.3)	7(20.0)		
2					0(0.0)	1(1.9)			0(0.0)	2(5.7)		
3					0(0.0)	0(0.0)			0(0.0)	0(0.0)		
LOS (d)	13.43±5.560	13.16±6.048	0.200	0.842	13.17±4.714	16.68±6.423	−3.207	0.002	13.31±4.739	17.34±9.753	−2.198	0.031
LPS (d)	7.62±4.159	7.32±5.287	0.269	0.789	6.94±3.255	9.64±5.023	−3.282	0.001	7.26±3.526	10.49±6.577	−2.560	0.013
Blood Transfusion												
No	28(75.7)	26(70.3)	0.274	0.601	44(83.0)	40(75.5)	0.918	0.338	28(80.0)	27(77.1)	0.085	0.771
Yes	9(24.3)	11(29.7)			9(17.0)	13(24.5)			7(20.0)	8(22.9)		
Pre-discharge PALBI Grade*												
Grade 1	5(20.8)	2(9.1)	1.910	0.425	5(13.5)	2(4.8)	3.699	0.147	5(20.0)	5(15.6)	0.187	0.911
Grade 2	12(50.0)	15(68.2)			22(59.5)	21(50.0)			11(44.0)	15(46.9)		
Grade 3	7(29.2)	5(22.7)			10(27.0)	19(45.2)			9(36.0)	12(37.5)		
Postoperative Complications												
0	24(64.9)	23(62.2)	0.325	1.000	36(67.9)	17(32.1)	13.747	0.001	24(68.6)	17(48.6)	3.099	0.266
1	12(32.4)	13(35.1)			16(30.2)	34(64.2)			10(28.6)	15(42.9)		
2	1(2.7)	1(2.7)			1(1.9)	2(3.8)			1(2.9)	3(8.6)		

(*Continued*)

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Table 5 (Continued).

Outcome Variable	PSM-OE Group 1 (n=37, %)	PSM-YE Group (n=37, %)	t/ χ^2	p1	PSM-OE Group 2 (n=53, %)	PSM-ONE Group (n=53, %)	t/ χ^2	p2	PSM-OE Group 3 (n=35, %)	PSM-YNE Group (n=35, %)	t/ χ^2	P3
AHC (RMB)	73244.06±42,870.02	68,041.15±37,567.27	0.555	0.580	67,643.98±28,831.86	72,481.44±40,022.11	−0.714	0.477	74,906.43±43,512.31	79,529.03±55,619.39	−0.387	0.700
Changes in PALBI Grade*												
−2	0(0.0)	1(4.5)	1.366	0.895	0(0.0)	1(2.4)	4.908	0.228	0(0.0)	1(3.1)	5.828	0.187
−1	6(25.0)	4(18.2)			9(24.3)	6(14.3)			6(24.0)	3(9.4)		
0	10(41.7)	9(40.9)			16(43.2)	13(31.0)			10(40.0)	15(46.9)		
1	8(33.3)	8(36.4)			12(32.4)	21(50.0)			9(36.0)	9(28.1)		
2	0(0.0)	0(0.0)			0(0.0)	1(2.4)			0(0.0)	4(12.5)		

Notes: *Only included the cases with available statistical values. Postoperative Pain:0 (No Pain), 1 (Mild Pain, 1~3), 2 (Moderate Pain, 4~6), 3 (Severe Pain, 7~10); Pre-discharge PALBI Grade*: Grade 1 (≤-2.53), Grade 2 (> −2.53 and ≤ −2.09), Grade 3 (>-2.09); Changes in PALBI Grade*: −2 (Significantly Improved), −1 (Mildly Improved), 0 (No Change), 1 (Mildly Worsened), 2 (Significantly Worsened); Postoperative Complications: 0 (No Complication), 1 (Grade ≤3), 2 (Grade >3); Postoperative complications were graded according to the Clavien-Dindo classification, with a three-tier grading framework established for standardized outcome assessment: Grade 0 (No Complication) denoted the absence of any postoperative adverse events; Grade 1 included mild complications corresponding to Clavien-Dindo grades ≤3; and Grade 2 represented acute severe complications equivalent to Clavien-Dindo grades >3.
Abbreviations: PSM, Propensity Score Matching; OE, Older adult Enhanced Recovery After Surgery; YE, Younger adult Enhanced Recovery After Surgery; ONE, Older adult non-Enhanced Recovery After Surgery; YNE, Younger adult non-Enhanced Recovery After Surgery; LOS, Lengths of Hospital Stays; LPS, Lengths of Postoperative Stays; AHC, Average Hospitalization Costs.

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Factors Affecting LOS

Univariate analysis demonstrated that ERAS, gender, perioperative blood transfusion, diabetes, postoperative complications, anemia, the PALBI score at admission, the PALBI score prior to discharge, alcohol history, portal occlusion method, the number of liver segments resected, laparoscopic surgery, and BCLC stage significantly influenced LOS. However, multivariate regression analysis indicated that ERAS (OR=1.733, p=0.038), the absence of perioperative blood transfusion (OR=2.280, p=0.011), HIO (as compared to Pringle method) (OR=2.488, p=0.030), MIH (OR=1.992, p=0.007), and BCLC stage A (as compared to BCLC stage C) (OR=2.670, p=0.016) were associated with a reduction in LOS.

Factors Affecting LPS

Univariate analysis identified ERAS, perioperative blood transfusion, postoperative complications, anemia, the PALBI score at admission, the PALBI score prior to discharge, alcohol history, repeat liver resection, the number of liver segments resected, laparoscopic surgery, and BCLC stage as factors influencing LPS. Nevertheless, multivariate regression analysis revealed that ERAS (OR=1.901, p=0.015), laparoscopic surgery (OR=1.938, p=0.009), and the absence of perioperative blood transfusion (OR=3.013, p=0.001) were significantly associated with reduced LPS.

Factors Affecting Average Hospitalization Costs

Univariate analysis revealed that gender, perioperative blood transfusion, history of other cancers, postoperative complications, anemia, PALBI score at admission, smoking history, alcohol history, repeat liver resection, the number of liver segments resected, laparoscopic surgery, and BCLC stage significantly influenced average hospitalization costs. Multivariate regression analysis identified female gender (OR=2.062, p=0.035), the absence of perioperative blood transfusion (OR=5.106, p<0.001), PALBI scores of 1 and 2 (compared to PALBI score 3, OR=3.292, p=0.001; OR=2.213, p=0.017), MIH (OR=0.425, p<0.001), and BCLC stages 0 and A (compared to BCLC stage C, OR=6.369, p=0.019; OR=2.950, p=0.005) as key factors associated with reduced average hospitalization costs.

Factors Affecting Postoperative Pain

Univariate analysis identified age, ERAS, perioperative blood transfusion, anemia, PALBI score at admission, PALBI score before discharge, portal occlusion method, and laparoscopic surgery as factors influencing postoperative pain. Multivariate regression analysis indicated that ERAS (OR=5.014, p=0.035) and Previous upper abdominal surgery (OR=62,509,748.425, p<0.001) were significant factors in minimizing postoperative pain, while ERAS (OR=4.854, p=0.043) was notably associated with the prevention of moderate to severe pain.

Factors Affecting Postoperative Complications

Univariate analysis highlighted age, ERAS, and repeat liver resection as critical factors influencing postoperative complications. Multivariate regression analysis demonstrated that ERAS (OR=5.235, p=0.021) and the absence of perioperative blood transfusion (OR=36.997, p<0.001) were crucial in preventing postoperative complications. Furthermore, no perioperative blood transfusion (OR=21.894, p<0.001) and the absence of portal occlusion (compared with total liver occlusion, OR=0.072, p=0.004) were important in reducing the risk of severe complications (grade 3 and above).

Discussion

To our knowledge, this study is rare in comparing the effects of ERAS protocols across different age groups in patients with HCC. The data indicate that ERAS application in OE Group was associated with lower postoperative pain, shorter LOS and LPS, and fewer complications compared to ONE Group. After PSM, OE patients had superior pain control than YE patients, and comparable outcomes to YE patients in other endpoints. These findings are especially relevant for older adult patients, who often face higher surgical risks due to comorbidities and age-related physiological decline.

ERAS has now been widely adopted in various surgical procedures, particularly among older populations, where its effectiveness has been validated.[21,22] In liver resection, ERAS also confers significant clinical benefits: preoperative oral carbohydrate loading and early postoperative oral feeding reduce acute-phase inflammation and alleviate symptom

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burden in older adult HCC patients.[12] Zhou et al[23] further confirmed via PSM analysis that ERAS improves pain control, reduces complications, and shortens LOS in 174 laparoscopic liver resection patients. Moreover, for the large population of cirrhotic HCC patients in China, Zheng et al[24] demonstrated ERAS safety and efficacy, though surgical factors (eg, procedure type) exert a greater impact on morbidity than other variables. Jiang et al[25] also reported ERAS-related reductions in LOS and postoperative complications in elderly hepatectomy patients. However, literature directly comparing ERAS outcomes between older and younger patients, or across ERAS/non-ERAS subgroups within different age groups, remains scarce - this gap is addressed in our study.

A core observation was the superior pain control of ERAS in elderly patients, as reflected by the significantly higher proportion of pain-free patients in the OE group versus the YE and ONE groups. This finding aligns with the core tenets of ERAS, which emphasizes multimodal analgesia strategies combining non-opioid analgesics, regional nerve blocks, and minimally invasive surgical techniques to reduce opioid consumption and related adverse events.[8,26] Given that elderly patients are more prone to opioid-induced constipation, delirium, and respiratory depression, ERAS's optimized analgesia not only alleviates pain but also minimizes geriatric-specific complications. The trend toward comparable pain status between the OE and YNE groups further indicates that ERAS can offset age-related recovery disadvantages, enabling elderly patients to achieve pain control similar to young patients receiving conventional care. Consistent with previous studies,[13,23] our data also confirm that ERAS does not impose additional burdens on liver reserve function - critical for hepatectomy patients, especially those with underlying liver diseases - supported by stable PALBI grade distributions and a favorable trend toward improved liver function.

The notably lower complication rate in the OE group compared with the ONE and YNE groups underscores the protective effect of ERAS against postoperative adverse events. For elderly patients with reduced physiological reserve and higher comorbidity burdens, ERAS's holistic approach (preoperative nutritional optimization, intraoperative minimally invasive techniques, and postoperative strict glycemic control)[6,9] collectively reduces complications such as wound infections, bile leaks, and pneumonia. The comparable complication rates between the OE and YE groups further validate ERAS's safety in the elderly, challenging the traditional notion that older patients are unsuitable for aggressive fast-track rehabilitation.[26,27] These benefits are further strengthened by multivariate regression analysis, which identifies ERAS as an independent predictor of favorable outcomes, beyond confounding factors such as blood transfusion and surgical approach.

Potential mechanisms underlying these findings include ERAS's comprehensive interventions: optimized pain management, respiratory exercises, early mobilization, and nutritional support. These measures alleviate surgical stress and mitigate unnecessary side effects—particularly critical for older adults with preexisting frailty or comorbidities. Early mobilization prevents muscle atrophy and thromboembolic events, while nutritional support enhances immune function and wound healing—components lacking systematic implementation in traditional care, which often leads to suboptimal pain control, delayed mobilization, and inadequate nutrition.[26,27]. Thus, ERAS protocols should be strongly advocated for older adult patients to facilitate rapid recovery.

Nevertheless, this study has several limitations. First, as a single-center retrospective study, it is inherently susceptible to selection bias and unmeasured confounding factors, despite PSM balancing baseline covariates. Second, the modest sample size of each matched cohort may limit statistical power to detect subtle differences in rare outcomes (eg, severe complications). Third, long-term follow-up data (eg, long-term liver dysfunction, quality of life, and overall survival) are lacking, which are essential for evaluating ERAS's long-term efficacy in the elderly. Finally, liver reserve function was primarily assessed via PALBI grade; integrating additional indicators such as indocyanine green retention rate could provide a more comprehensive evaluation.

Conclusion

Our study provides compelling evidence that ERAS protocols are safe and effective for elderly patients with HCC undergoing hepatectomy, yielding significant benefits in pain control, hospitalization duration reduction, and complication prevention—without increasing medical costs or impairing liver reserve function. These results support the recommendation of ERAS as the standard perioperative management strategy for elderly HCC patients. Future multicenter prospective randomized controlled trials with larger sample sizes and long-term follow-up are warranted to validate these findings and further refine ERAS protocols to better meet the specific needs of the elderly population.

Data Sharing Statement

All data generated or analyzed during this study are included in this published article.

Statement of Ethics

Study approval statement: This study was conducted in accordance with the Declaration of Helsinki and approved by Sichuan Provincial People's Hospital (Ethics Review [Res.] No. 192, 2023).

Author Contributions

All authors made a significant contribution to the work reported, whether that is in the conception, study design, execution, acquisition of data, analysis and interpretation, or in all these areas; took part in drafting, revising or critically reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

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Disclosure

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