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Original Article

Nursing-led stepwise pain-management protocol improves postoperative outcomes after hepatobiliary surgery

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Abstract: Objective: To assess the impact of a stepwise pain-management protocol on postoperative recovery, pain control, complication rate, and resource utilization in patients undergoing hepatobiliary surgery. Methods: This retrospective cohort study included 222 patients undergoing elective hepatobiliary surgery. Patients were assigned to a control group (n = 112) and an observation group (n = 110). The control group received routine care, while the observation group received a stepwise pain-management protocol. The primary outcome was postoperative pain intensity measured at different time points using the Numerical Rating Scale (NRS). Secondary outcomes included gastrointestinal recovery, complications, medical resource utilization, and quality of recovery, assessed using the QoR-40 questionnaire. Results: The stepwise pain-management protocol significantly improved perioperative outcomes. Patients in the observation group had lower NRS scores (including peak pain and activity-induced pain) at all postoperative time points (all $P < 0.001$). Gastrointestinal recovery was faster, and nausea scores were lower ($P < 0.001$). Hospital stay, ICU stay, nursing workload, and number of monitoring alarms were reduced (all $P \leq 0.001$). Opioid consumption and patient-controlled analgesia usage decreased, while early mobilization ability, physical function, QoR-40 score, and safety all improved (all $P < 0.001$). Multivariate regression analysis confirmed that this regimen was an independent predictor of pain reduction ($\beta = -2.155$, $P < 0.001$). Conclusion: This study demonstrates that a series of pain management protocols can significantly improve postoperative outcomes in patients undergoing hepatobiliary surgery, reduce pain, shorten recovery time, and decrease complications.

Keywords: Stepwise pain management, enhanced recovery, hepatobiliary surgery, postoperative care, clinical outcomes

Introduction

One characteristic of liver and biliary tract surgery is the severe postoperative pain resulting from extensive tissue movement, large incisions, and prolonged operation time [1]. Poor pain management not only exacerbates patient pain but also leads to impaired respiratory functions, decreased mobility, and enhanced neuroendocrine activity, ultimately prolonging recovery time. With the increasing adoption of Enhanced Recovery After Surgery (ERAS) pathways worldwide, postoperative analgesia is now considered a key element for achieving rapid functional recovery and minimizing perioperative morbidity [2, 3]. Although the ERAS principle is gaining popularity in hepatobiliary surgery, the most effective pain control strategy for this population remains controversial.

Traditional analgesia methods, especially those heavily reliant on opioids, can cause adverse reactions such as respiratory depression, intestinal obstruction, nausea, and delayed activity, which conflict with the goals of ERAS [4-6]. Therefore, multimodal analgesia has attracted attention due to its potential to reduce opioid use and improve patient comfort. However, a standardized, graded, and dynamic pain management model tailored to the physiological complexities of hepatobiliary surgery has not yet been established. Against this backdrop, we propose a nursing-led, stepwise pain management protocol, defined as a structured, nurse-led, multimodal analgesia strategy that includes: (1) the use of standardized pain assessment tools at predetermined time points; (2) adjusting analgesia intensity according to clearly defined steps based on pain scores and clini-

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cal recovery indicators; (3) prioritizing non-opioid and regional blockade techniques, with opioids used only for remediation or to address higher pain scores; and (4) emphasizing ongoing patient education and close multidisciplinary communication. Stepwise enhancement (or reduction) of analgesia interventions based on these principles provides a personalized and responsive approach to pain control. Nevertheless, the effectiveness of this nursing-led, stepwise protocol in organized ERAS program for hepatobiliary surgery remains unclear.

Existing literature is fragmented, with most studies focusing on isolated analgesic modalities rather than comprehensive, algorithmic systems [7-9]. Therefore, the theoretical advantages of stepwise analgesia, including better pain control, reduced opioid exposure, improved mobility, and shorter hospital stays, have not been adequately investigated in this patient population. Filling this knowledge gap is crucial for improving ERAS pathways and maximizing surgical outcomes. Therefore, this study aimed to evaluate the clinical significance of progressive pain management guidelines for postoperative recovery measures in the ERAS framework. By standardizing assessments of postoperative pain, functional recovery, complication rates, and length of hospital stay, we aimed to investigate whether adopting patient-responsive analgesia methods based on a systematic understanding of postoperative outcomes can have a meaningful impact. It is anticipated that our findings will contribute to providing high-quality evidence to guide perioperative practice and promote the further development of ERAS guidelines.

Methods

Case section

This retrospective cohort study included 222 consecutive patients who underwent elective hepatobiliary surgery at Linyi People's Hospital between January 2023 and October 2025. All eligible cases were identified using the institution's electronic medical record system and perioperative anesthesia database. Based on nursing and anesthesia records, patients received different postoperative pain management protocols and were assigned to two groups: a control group (n = 112) and an observation group (n = 110). All data were anonymized, and written informed consent was not required. This study was approved by the Ethics Committee of Linyi People's Hospital, and all procedures complied with the Declaration of Helsinki.

Inclusion criteria: Patients were eligible for inclusion if they met all the following criteria: 1. They had undergone laparoscopic or open hepatobiliary surgeries, including hepatic resections, biliary construction, and cholecystectomy combined with common bile duct exploration; 2. They received first-time surgery during the study period to avoid multiple measurements of the same individual; 3. They had fully completed perioperative records (at minimum during the index hospitalization), including anesthesia records, nursing records, and postoperative follow-up records.

Exclusion criteria: Patients were excluded from the study if they met any of the following criteria: 1. They underwent emergency surgery or reoperative surgery due to postoperative complications; 2. They required ICU admission due to hemodynamic instability or organ failure; 3. They had severe cognitive deficits, psychiatric conditions, or language barriers that prevented accurate pain evaluation using standard scales; 4. They had a history of chronic opioid use or substance abuse; 5. They lacked complete key clinical information (e.g., missing pain scores or analgesic records); 6. They died during the initial hospitalization due to catastrophic surgical or medical complications (as their recovery pattern was inconsistent with that of the overall ERAS patients).

Data collection

Patients who underwent hepatobiliary surgery at the same facility were prospectively followed up. To ensure comparability between the observation and control groups, baseline demographic and clinical data (age, sex, body mass index, smoking history, alcohol consumption history, and comorbidities such as hypertension and diabetes) were collected. Surgical-related factors were also recorded, including American Society of Anesthesiologists (ASA) classification, type of surgery (open or laparoscopic), hepatectomy, and biliary reconstruction. Postoperative pain intensity was assessed using the 0-10 Numerical Rating Scale (NRS) at

pre-defined time points of 6, 24, 48, and 72 hours postoperatively; resting pain and activity-induced pain were also recorded at 24 hours postoperatively. Gastrointestinal recovery parameters (time to first flatus, first bowel movement, and first oral intake) and the incidence of postoperative complications were recorded at the corresponding time points. Resource utilization was assessed by length of hospital stay, length of stay in the intensive care unit, number of daily nursing interventions, and analgesia-related workload. Quality of recovery was assessed using the total score and domain scores of the 40-item Quality of Recovery Rating Scale (QoR-40).

Outcome measure

The primary outcome measure was postoperative pain intensity, measured using NRS (0-10) at pre-defined time points of 6, 24, 48, and 72 hours postoperatively. At each time point, patients were required to report their maximum pain intensity since the last assessment, and resting pain and activity-induced pain were specifically recorded at 24 hours postoperatively. Secondary outcome measures included gastrointestinal function recovery (expressed as time to first flatus, first bowel movement, and first oral intake) and postoperative nausea score. Postoperative complications were defined according to standardized clinical definitions and included pulmonary infection, wound infection, bile leakage, deep vein thrombosis, and reoperation. Healthcare resource utilization measures included total length of hospital stay, ICU stay, frequency of nursing interventions, analgesia workload index per patient, resources allocated to managing complications, and number of daily monitoring alerts. Patient-centered recovery was assessed using the QoR-40, a validated tool that assesses physical, psychological, and social domains, as well as patient satisfaction with pain management and perioperative care. To explore the determinants of pain reduction, multivariate regression analysis was employed, including the procedure, surgical method, and duration of surgery as candidate predictive factors.

Statistical analysis

Statistical analysis was performed using SPSS version 23.0. The normality of continuous variables was assessed using the Shapiro-Wilk test, and independent samples t-tests or Mann-Whitney U tests were used for comparison as appropriate. Categorical variables were analyzed using the χ^2 test or Fisher's exact test. To identify independent predictors of pain reduction, a multivariate linear regression model was constructed using clinically relevant covariates and variables with $P < 0.10$ in the univariate analysis. Effect estimates were expressed as β coefficients and 95% confidence intervals. All statistical tests were two-tailed, and the significance level was set at $P < 0.05$.

Results

Baseline clinical characteristics

The two groups were comparable in terms of age ($P = 0.333$), sex distribution ($P = 0.912$), BMI ($P = 0.353$), smoking history ($P = 0.631$), alcohol consumption history ($P = 0.943$), and comorbidities, including hypertension ($P = 0.752$) and diabetes mellitus ($P = 0.813$). Surgical characteristics, such as ASA classification III-IV ($P = 0.701$), open surgery ($P = 0.693$), hepatectomy ($P = 0.878$), and biliary reconstruction ($P = 0.931$), were also balanced between the two groups (**Table 1**).

Pain scores

The observation group showed significantly lower NRS scores at all postoperative time points, with a lower early peak and a faster decline within 72 hours (all $P < 0.05$). The maximum NRS score during hospitalization was significantly reduced ($P < 0.001$), and activity-induced pain 24 hours postoperatively was significantly alleviated ($P < 0.001$) (**Figure 1**). Overall, the stepwise pain-management protocol effectively decreased both static and dynamic pain following the hepatobiliary surgery.

Gastrointestinal function recovery

Compared to the control group, the observation group showed significantly shorter times for first flatus, first bowel movement, and first food intake, and a significantly lower postoperative nausea score (all $P < 0.001$) (**Figure 2**). These consistent improvements indicate that the stepwise pain-management protocol effectively promoted the recovery of bowel function

Table 1. Baseline clinical characteristics

Variables	Control Group (n = 112)	Observation Group (n = 110)	X^2/t	*P*-value
Age (years)	59.96 ± 11.72	58.56 ± 9.63	0.970	0.333
Male (%)	67 (59.82%)	65 (59.12%)	0.012	0.912
BMI (kg/m^2)	24.31 ± 3.56	24.72 ± 3.08	0.930	0.353
Smoking history (%)	38 (33.92%)	34 (30.92%)	0.231	0.631
Alcohol consumption (%)	30 (26.81%)	29 (26.41%)	0.005	0.943
Hypertension (%)	42 (37.53%)	39 (35.53%)	0.100	0.752
Diabetes (%)	28 (25.02%)	26 (23.62%)	0.056	0.813
Coronary artery disease (%)	9 (8.04%)	11 (10.01%)	0.261	0.609
Chronic liver disease (%)	15 (13.44%)	17 (15.51%)	0.191	0.662
ASA class III-IV (%)	29 (25.93%)	31 (28.22%)	0.147	0.701
Open surgery (%)	61 (54.52%)	57 (51.83%)	0.156	0.693
Hepatectomy (%)	49 (43.83%)	47 (42.73%)	0.024	0.878
Biliary reconstruction (%)	26 (23.21%)	25 (22.74%)	0.007	0.931

Note: BMI: body mass index.

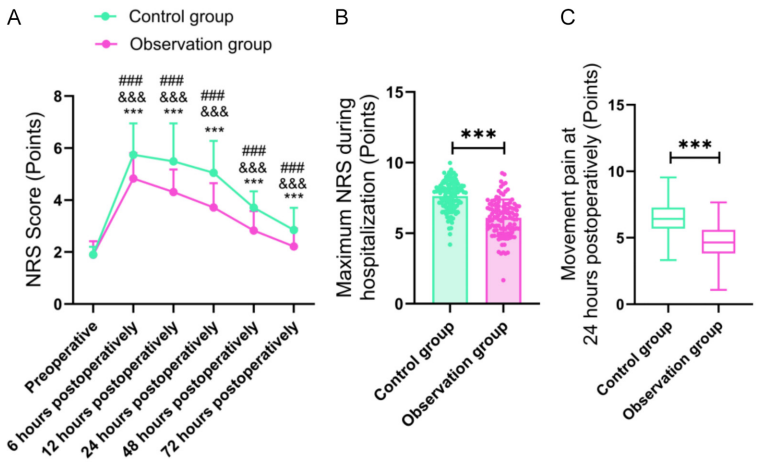

Figure 1. Comparing pain scores between the two groups. (A) NRS score, (B) Maximum NRS during hospitalization, (C) Movement pain at 24 h. Compare to the control group, ***P < 0.001. Compare to the control group at preoperative, &&&P < 0.001. Compare to the observation group at preoperative, ###P < 0.001. Note: NRS: Numeric Rating Scale.

in patients after hepatobiliary surgery and accelerated the overall recovery process.

Postoperative complications

The incidence of postoperative complications was lower in the observation group than that in the control group, with the overall complication rate decreasing from 28.61% to 16.36% (P = 0.029). The incidence of pulmonary infection was also significantly lower in the observation group (12.53% vs. 4.52%, P = 0.029). Other complications, such as wound infection (8.02% vs. 4.52%, P = 0.285), bile leakage (5.42% vs. 3.61%, P = 0.537), deep vein thrombosis (4.53% vs. 1.81%, P = 0.259), and reoperation (2.71% vs. 0.92%, P = 0.322), showed no statistically significant differences between the two groups (all P > 0.05) (**Table 2**).

Hospital stay and resource utilization

Compared to the control group, the observation group required fewer medical resources (**Table 3**). Hospital stay and ICU stay were shorter (both P ≤ 0.001), and the number of daily nursing interventions, analgesia-related workload index, complication-related resource usage, and total daily monitoring alarms were all significantly reduced (all P < 0.001).

Quality of recovery

After the intervention, the observation group had a significantly higher QoR-40 total score than the control group, and also better scores in physical, psychological, and social recovery (all P < 0.001). Patient-reported outcomes further supported these findings: the observation group showed significantly improved pain control satisfaction and overall satisfaction, while the improvement in the control group was more moderate (both P < 0.05, **Figure 3**).

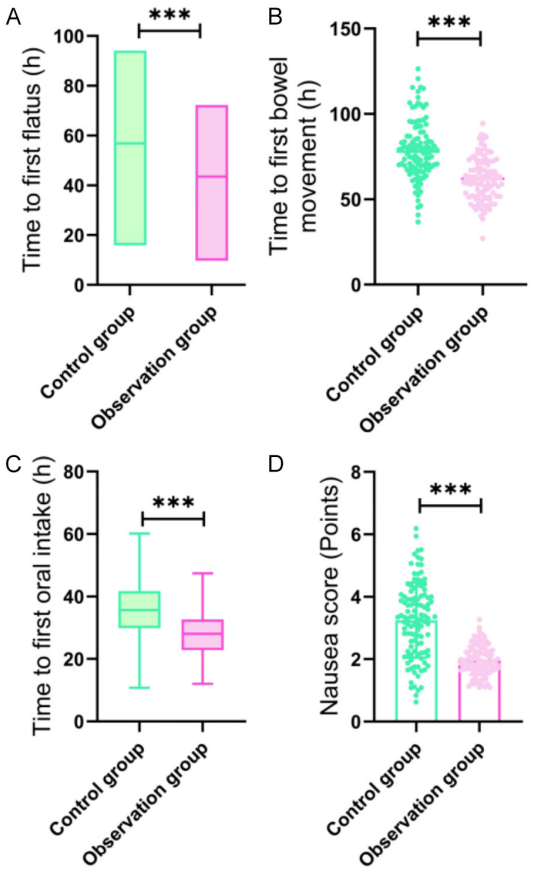

Figure 2. Comparing gastrointestinal functional recovery between the two groups. (A) Time to first flatus, (B) Time to first bowel movement, (C) Time to first oral intake, (D) Nausea score. Compare to the control group, ***P < 0.001.

Analgesic pharmacodynamics and opioid-sparing indicators

Compared to the control group, the observation group had a lower total opioid usage within 72 hours, fewer rescue analgesic administrations, and a longer time to the first rescue administration (all P < 0.001). The observation group had a higher cumulative dose of nonsteroidal anti-inflammatory drugs (NSAIDs), but lower usage of antiemetics related to postoperative nausea and vomiting, and fewer triggers of patient-controlled analgesia (all P < 0.001). On postoperative day 1, the observation group had a higher sedation score (P < 0.001) (**Table 4**).

Safety and analgesia-related adverse events

The observation group showed a more favorable safety profile than the control group, with significantly lower incidences of pruritus (P = 0.038) and dizziness (P = 0.039), and a decreasing trend in the incidence of intestinal obstruction lasting more than 72 h, but this was not statistically significant (P = 0.054). Other adverse events related to opioids or their treatment, including urinary retention (P = 0.092), opioid-induced respiratory depression (4.52% vs. 0.92%, P = 0.102), sedation requiring intervention (P = 0.094), drug-related allergic reactions (P = 0.322), and unplanned return to the ICU (P = 0.181), were also less common in the observation group, but these differences were not statistically significant (all P > 0.05) (**Table 5**).

Early mobilization & physical function

The observation group had significantly shorter times to get out of bed and walk ≥ 10 meters, and more steps per day on postoperative day 2 (both P < 0.001). On postoperative day 3, the observation group also showed better functional performance, including Barthel activity level, lower limb muscle strength, and balance test scores (all P < 0.001). In addition, patients in the observation group experienced fewer episodes of dizziness and lower fall risk scores within 48 hours (both P < 0.001) (**Table 6**).

Multivariate regression analysis predicting pain reduction

Multivariate regression analysis revealed that the stepwise pain management approach was the strongest predictor of pain reduction (β = -2.155, 95% CI: 0.056 to 0.239, P < 0.001), significantly reducing pain scores within 24 hours postoperatively. Moreover, compared to laparoscopic surgery, open surgery was associated with greater pain reduction (β = +0.426, 95% CI: 1.359 to 1.727, P < 0.001). Longer surgical duration also contributed to pain relief (β = +1.302, 95% CI: 1.757 to 7.689, P = 0.001) (**Table 7**).

Discussion

Previous studies have confirmed that a stepwise protocol to pain management can significantly improve perioperative outcomes and increase the rate of rapid recovery in hepatobiliary surgery patients. Compared with traditional analgesia, this approach can also reduce pain scores at all postoperative time points, accelerate gastrointestinal function recovery,

Table 2. Comparing postoperative complication between the two groups

Complication Type	Control	Observation	X^2	*P*-value
Overall complications (%)	28.61%	16.36%	4.740	0.029
Pulmonary infection (%)	12.53%	4.52%	4.744	0.029
Wound infection (%)	8.02%	4.52%	1.144	0.285
Bile leak (%)	5.42%	3.61%	0.382	0.537
DVT (%)	4.53%	1.81%	1.272	0.259
Reoperation (%)	2.71%	0.92%	0.982	0.322

Note: DVT: deep vein thrombosis.

reduce the number of complications, shorten hospital and ICU stays, and reduce resource consumption. Notably, these objective improvements are accompanied by an increase in QoR-40 scores and patient-reported satisfaction, indicating that this strategy improves both the physiological and subjective aspects of recovery. In summary, our findings suggest that optimizing pain management through a standardized, multimodal, and dynamically adjusted pathway is a key driver for improving the effectiveness of ERAS in complex hepatobiliary surgery.

Our findings on pain are consistent with previous studies and further confirm that multimodal, standardized analgesia can reduce acute postoperative pain and reduce opioid use in large abdominal surgery [10-12]. The ERAS guidelines and randomized trials also indicate that combined regional blockade, non-opioid adjuvants, and personalized titration can reduce the initial noxious stimulus burst and facilitate patient mobility [13]. However, many reports on protocols show that while initial pain scores improve, the improvement is limited and often only assessed at a single time point (e.g., 24 hours) rather than sustained regulation over the initial 72 hours. In our observational group, the early NRS peak was significantly reduced, with a more pronounced downward trend throughout the 72 hours, and the highest NRS score during hospitalization was lower, along with less activity-induced pain. Mechanistically, sustained suppression of nociceptive input may inhibit nociceptive central sensitization and secondary hyperalgesia, thereby avoiding the potential pain crisis following major hepatobiliary surgery [14]. This clinical model is crucial: early severe pain is associated with delayed activity, poor respiratory function, and a high risk of chronic postoperative pain. Therefore, these data support the view that protocols should focus on following patterns of pain variation rather than isolated time-point scores, and underscore the need for a preventative rather than reactive approach to analgesia monitoring and control. The improved gastrointestinal function recovery rate in our protocol is consistent with published ERAS results for colorectal and upper gastrointestinal protocols, in which optimized analgesia (including protocols with reduced opioid use) is associated with earlier bowel function recovery and shorter postoperative paralytic ileus time. Multiple studies have shown that systemic opioids delay gastric emptying, inhibit intestinal motility, and prolong the time to first flatus and oral feeding [15, 16]. In contrast, multimodal protocols utilizing regional blockade, NSAIDs, acetaminophen, and adjuvant drugs such as gabapentin can reduce μ-opioid receptor-mediated intestinal motility disorders while maintaining effective analgesia. Our study applied this protocol to hepatobiliary surgery - a complex and high-risk procedure not yet included in ERAS trials. The stepwise protocol significantly shortened the time to first flatus, first defecation, and first oral feeding, and reduced nausea scores, indicating that the stepwise protocol mitigates the effects of the opioid-intestinal barrier (which often limits early feeding in this population). In fact, this provides a basis for more proactive implementation of enteral nutrition in the ERAS pathway of hepatobiliary surgery, while also reminding us that even if pain scores seem satisfactory, traditional opioid-based analgesia methods may still have a potential inhibitory effect on gastrointestinal recovery.

The reduction in the number of postoperative complications, particularly pulmonary infections, may reflect the systemic benefits of this phased, nursing-led pain management pathway. Effective control of movement-induced pain is central to maintaining efficient respiratory mechanisms: as Harris et al. demonstrated [17], higher early postoperative pain scores were associated with reduced cough, shallow and rapid breathing, and decreased use of incentive spirometers, all of which predispose patients to atelectasis and pneumonia after

Table 3. Comparing hospital stay and resource utilization between the two groups

Variables	Control	Observation	t	*P*-value
Length of stay (days)	10.92 ± 2.54	8.85 ± 2.00	6.729	< 0.001
ICU stay (h)	18.68 ± 6.14	13.77 ± 5.01	6.512	< 0.001
Daily nursing interventions (times)	14.56 ± 3.10	10.70 ± 4.14	7.873	< 0.001
Analgesia-related workload index	5.40 ± 1.62	3.99 ± 0.10	9.124	< 0.001
Complication-related resource use	1.99 ± 0.09	1.00 ± 0.01	10.000	< 0.001
Total monitoring alarms/day	9.59 ± 3.06	6.84 ± 2.86	6.917	< 0.001

Note: ICU: intensive care unit.

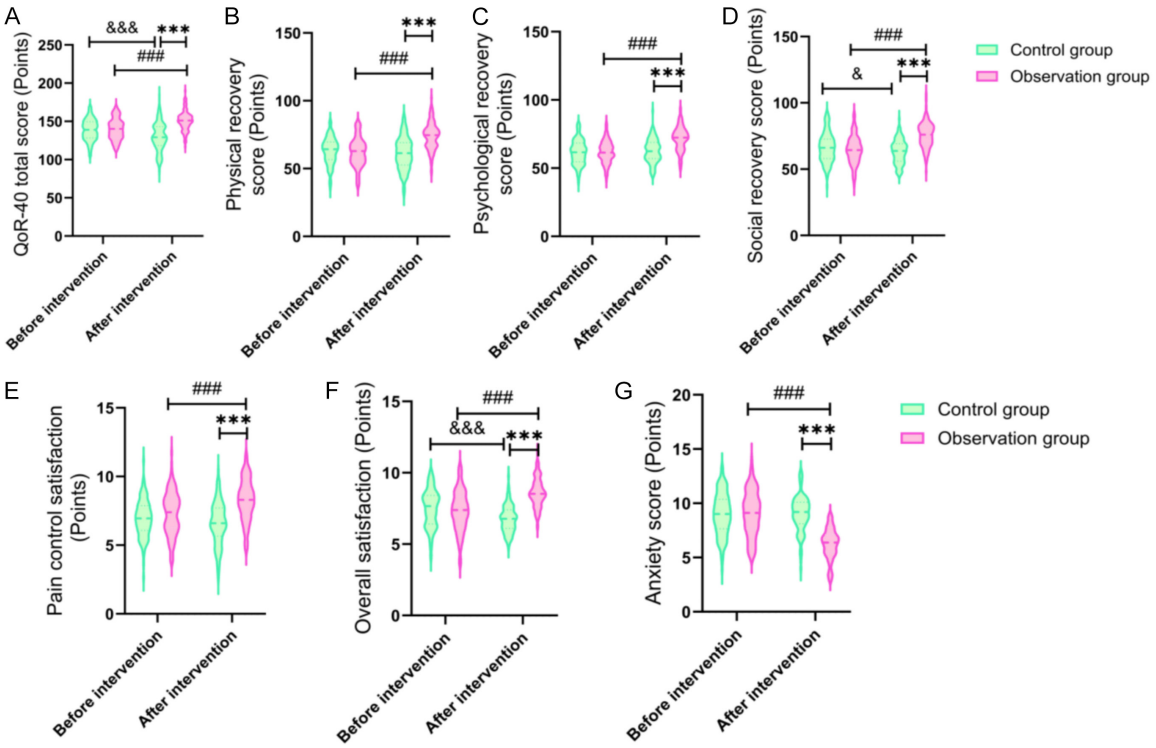

Figure 3. Comparing quality of recovery between the two groups. (A) QoR-40 total score, (B) Physical recovery score, (C) Psychological recovery score, (D) Social recovery score, (E) Pain control satisfaction, (F) Overall satisfaction, and (G) Anxiety score. Compare to the control group, ***P < 0.001. Compare to the control group before intervention, $^{\&}$P < 0.05, $^{\&\&\&}$P < 0.001. Compare to the observation group before intervention, $^{\#\#\#}$P < 0.001. Note: QoR-40: Quality of Recovery-40.

Table 4. Comparing analgesic pharmacodynamics and opioid-sparing indicators between the two groups

Variable	Control	Observation	t/X^2	*P*-value
Total opioid dose 72 h (MME)	92.40 ± 28.26	56.08 ± 21.87	10.696	< 0.001
Rescue analgesia frequency (/72 h)	3.38 ± 0.96	2.00 ± 0.01	15.105	< 0.001
Time to first rescue dose (h)	5.79 ± 2.24	10.39 ± 3.84	10.941	< 0.001
NSAID cumulative dose (mg)	320.47 ± 89.11	440.65 ± 89.47	10.026	< 0.001
PONV-related antiemetic dose	2.31 ± 0.59	1.00 ± 0.01	23.507	< 0.001
PCA triggers (/24 h)	14.29 ± 3.05	7.93 ± 2.63	16.654	< 0.001
Sedation score (RASS) POD1	-0.57 ± 0.56	-0.15 ± 0.40	6.459	< 0.001

Note: MME: morphine milligram equivalents; NSAID: nonsteroidal anti-inflammatory drug; PONV: postoperative nausea and vomiting; PCA: patient-controlled analgesia; RASS: Richmond Agitation-Sedation Scale; POD1: postoperative day 1.

Table 5. Comparing safety and analgesia-related adverse events between the two groups

Variable	Control	Observation	t/X^2	*P*-value
Pruritus (%)	18.72%	9.12%	4.310	0.038
Urinary retention (%)	14.33%	7.31%	2.831	0.092
Dizziness (%)	26.82%	15.51%	4.270	0.039
Ileus > 72 h (%)	11.62%	4.52%	3.714	0.054
Opioid-induced respiratory depression (%)	4.52%	0.92%	2.667	0.102
Sedation requiring intervention (%)	6.24%	1.82%	2.802	0.094
Drug-related allergic reaction (%)	2.71%	0.92%	0.982	0.322
Unplanned ICU return (%)	3.64%	0.92%	1.787	0.181

Note: ICU: intensive care unit.

Table 6. Comparing early mobilization and physical function between the two groups

Variable	Control	Observation	t	*P*-value
Time-to-off-bed (h)	25.26 ± 6.47	14.56 ± 5.25	13.516	< 0.001
Time-to-walk ≥ 10 m (h)	38.84 ± 11.81	28.28 ± 8.46	7.648	< 0.001
Daily steps POD2	855.81 ± 5.78	1010.73 ± 6.23	192.160	< 0.001
Barthel mobility score POD3	58.49 ± 9.54	70.91 ± 8.89	10.029	< 0.001
Lower-limb muscle strength grade	3.60 ± 0.83	4.21 ± 0.72	5.850	< 0.001
Dizziness episodes (/48 h)	3.10 ± 1.14	1.72 ± 0.81	10.371	< 0.001
Balance test score	13.04 ± 2.27	16.75 ± 3.38	9.597	< 0.001
Fall risk score	45.32 ± 8.18	36.89 ± 6.26	8.611	< 0.001

Note: POD2: postoperative day 2; POD3: postoperative day 3.

Table 7. Multivariable regression predicting pain reduction (ΔNRS 0-24 h)

Variable	β Coefficient	95% CI	*P*-value
Stepwise pain-management (yes/no)	-2.155	0.056 to 0.239	< 0.001
Surgical approach (open vs. lap)	+0.426	1.359 to 1.727	< 0.001
Duration of surgery (per 30 min)	+1.302	1.757 to 7.689	0.001

upper abdominal surgery [17-19]. By reducing dynamic pain during coughing, deep breathing, and activity, our stepwise approach may have facilitated more effective ventilation and sputum clearance, thereby lowering the incidence of pulmonary infections. In addition, the protocol was associated with earlier ambulation, faster bowel function recovery, and reduced nausea and vomiting. These changes contribute to faster recovery of mobility, improved diaphragmatic movement and ventilation-perfusion matching, and reduced risk of aspiration. Although the reduction in other complications (wound infection, bile spillage, deep vein thrombosis, and reoperation) was primarily numerical, the overall decrease in the complication burden suggests that effective pain management is a ERAS intervention that simultaneously promotes early mobilization, breathing exercises, nutritional intake, and physical therapy involvement. These findings highlight that inadequate postoperative pain management is not merely an inconvenience but a modifiable determinant of significant clinical morbidity.

Our data on length of hospital stay and resource usage are consistent with reports that strict adherence to ERAS principles translates into significant cost savings and improved workflow efficiency. Extensive literature in colorectal, pancreatic, and hepatic surgery has demonstrated that optimized pain, fluid, nutrition, and activity management can result in shorter hospital stays and less ICU usage. This stepwise pain management protocol alone reduced hospital stay by more than two days, average ICU stay by nearly four hours, average daily nursing interventions by less than five, analge-

sia-based workload, and monitoring alerts [20]. Mechanistically, patients with well-controlled and stable analgesia require fewer rescue medications, fewer pain assessments, and fewer high acuity levels and escalations to high acuity monitoring. This unspoken reduction in workload is not frequently measured in clinical trials but has significant implications for staff burnout and facility capacity. Our conclusion is that pain management and nursing workload measures should be incorporated into ERAS quality measures, and it is important to note that seemingly similar analgesia programs in terms of pain score control can have vastly different operational impacts.

Improvements in symptom quality, as measured by QoR-40 and patient-reported satisfaction, reflect a broader impact of quality of pain management on patient recovery than older clinical outcome measures [21, 22]. Previous findings suggest that the QoR-40 is a sophisticated, patient-centered measure for assessing physical comfort, emotional distress, psychological support, bodily autonomy, and pain. Improved QoR-40 scores were associated with fewer unplanned readmissions and improved long-term functional outcomes [23, 24]. In our study, simultaneous improvements in the total QoR-40 score and scores in the physical, psychological, and social domains suggest that the stepwise protocol facilitated more comprehensive recovery, likely due to its reduction of anxiety, increased patient sense of control, and enhanced patient-caregiver and family interaction. Mechanistically, this may break the vicious cycle where severe pain exacerbates anxiety and catastrophic thinking, which in turn increases perceived pain [25]. These observations serve as a warning to practitioners not to overemphasize numerical pain measurements while neglecting the psychological and social aspects of recovery; processes such as enhanced predictability, collaborative decision-making, and the expression of expectations regarding pain may be the most important aspects of treatment decisions.

Although several safety outcomes, such as urinary retention, opioid-induced respiratory depression, and the need for interventional sedation, did not reach conventional statistical significance, the sustained numerical reductions observed in the observation group may still be clinically significant. This stepwise, opioid-reducing protocol resulted in a lower incidence of these events, suggesting a potential reduction in bladder dysfunction and cardiopulmonary impairment, which is particularly important for older patients or those with comorbidities who are more susceptible to such adverse effects. Moreover, the reduced trend of drug-related allergic reactions and unplanned ICU returns, consistent with a significant decrease in itching, dizziness, bowel obstruction > 72 h, and unplanned emergency calls, indicates a more stable and predictable postoperative course. While this study may not have been able to detect statistically significant differences in these relatively rare events due to insufficient sample size, the overall pattern supports the hypothesis that a nursing-led stepwise pain management pathway not only improves analgesia but may also enhance clinical safety - a hypothesis that should be validated in larger, multicenter studies.

Our findings should also be interpreted in conjunction with existing ERAS-oriented pain management protocols. Similar to previously reported ERAS pathways, our approach employs a multimodal, opioid-reduced analgesia approach, emphasizing early mobilization, early oral feeding, and systemic pain assessment. However, this protocol differs from most previous ERAS pain management protocols in several ways. First, it employs a clearly defined, phased, stepwise algorithm where escalation and de-escalation of analgesia intensity are explicitly linked to pain scores and functional milestones (such as effective coughing, deep breathing, and ambulation), rather than relying solely on physician-led ad hoc adjustments. Second, the pathway is primarily led and implemented by the nursing team, with bedside nurses having the authority to implement pre-set analgesia modalities and dosage adjustments in real time, potentially shortening response times to poor pain control and improving protocol adherence. Third, the protocol integrates routine reassessment of dynamic (motor-induced) pain with concurrent breathing exercises and activity goals, thus more closely linking analgesia to key components of ERAS. These characteristics differentiate our phased approach from traditional ERAS pain protocols and may help explain the improvements observed in analgesia and postoperative complications.

Several limitations of this study need to be considered. First, despite multivariate adjustment, our study was not a blinded randomized controlled trial, thus there is a possibility of residual confounding and implementation bias; we cannot determine whether clinicians were unaffected by the protocol and modified other care interventions, such as activity or fluid management, which could also affect recovery. Second, this study was conducted at a single center with expertise in hepatobiliary surgery and ERAS implementation, which may not be generalizable to institutions with limited resources or practices with different backgrounds. Third, we focused on early postoperative discharge outcomes and did not assess long-term outcomes related to chronic postoperative pain, health-related quality of life, or initial postoperative cost-effectiveness. Fourth, NRS and QoR-40 are validated tools, they are susceptible to reporting errors, cultural factors, and differences in patient expectations. Lastly, we have not fully evaluated opioid use, regional blockade success rates, and adherence to each component of the protocol, which would be helpful in understanding which components contributed to the listed benefits.

In conclusion, this study provides substantial data demonstrating that a stepwise, protocolized, pain-management program is highly beneficial for accelerating recovery after hepatobiliary surgery. Lower pain scores, faster gastrointestinal recovery, fewer complications, shorter hospital and ICU stays, reduced resource utilization, and patient-reported better quality of recovery appear to make this protocol a key integrative system across many aspects of ERAS. These results help integrate structured pain pathways into the core of hepatobiliary surgery ERAS programs and emphasize the importance of future multicenter randomized trials to address the various elements of this protocol, study long-term outcomes, and cost-effectiveness. In the absence of such data, our findings suggest that a systematic and team-based approach to pain management may yield significant clinical and operational benefits for patients undergoing complex hepatobiliary surgery.

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Disclosure of conflict of interest

None.

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