Application of Multimodal Pain Management Protocols Following Pediatric Liver Transplantation

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AIM: To develop and implement a pain management program aimed at improving pain control and promoting postoperative recovery following liver transplantation in pediatrics.

METHODS: This study was a retrospective analysis of 95 children who underwent liver transplantation between May 2020 and May 2025. Patients were divided into observation and control groups according to the actual postoperative pain management plan they received. The observation group received a multimodal analgesia protocol incorporating both drug and non-drug interventions. Pain was assessed regularly, and corresponding interventions were implemented as needed. The control group received conventional analgesic management. Pain score, recovery time, and family satisfaction were the primary outcome measures. Independent-sample *t*-tests and chi-square tests were used for between-group comparisons.

RESULTS: Pain scores in the observation group were significantly lower than those of the control group during the T3–T7 stages (the afternoon of the first postoperative day, and T7 refers to the afternoon of post operative day 3) ($p < 0.05$). Time to ambulation was significantly shorter in the observation group ($p = 0.002$), with shorter hospitalization duration ($p = 0.004$) than those in the control group. Pain-related stress indicators also improved significantly in the observation group ($p < 0.05$). Additionally, significant differences were observed between the two groups regarding the distribution of satisfaction levels for nursing rounds ($p = 0.030$) and health education ($p = 0.005$).

CONCLUSIONS: The postoperative pain management program for pediatric liver transplantation effectively alleviates postoperative pain through multimodal analgesia, shortens recovery time, and improves family satisfaction. This approach shows substantial clinical value and may serve as a reference for standardizing pain management in children post-liver transplantation.

Keywords: liver transplantation; children; pain management; nursing care

Introduction

Currently, liver transplantation has become a routine treatment for children with end-stage liver failure. With advances in medical technology, the long-term postoperative survival rate for children has improved substantially [1]. However, pediatric liver transplantation is relatively complicated and time-consuming. Intraoperative factors such as retractor traction, postoperative drainage tube placement, and bilateral subcostal incisions extending to the xiphoid process can lead to postoperative pain. Singh *et al*. [2] reported that the incidence of pain at 5 h, 2 days, and 3 days after abdominal surgery was 84.2%, 92.5%, and 96.7%, respectively. Over 85% of children experience postoperative pain after surgery [3].

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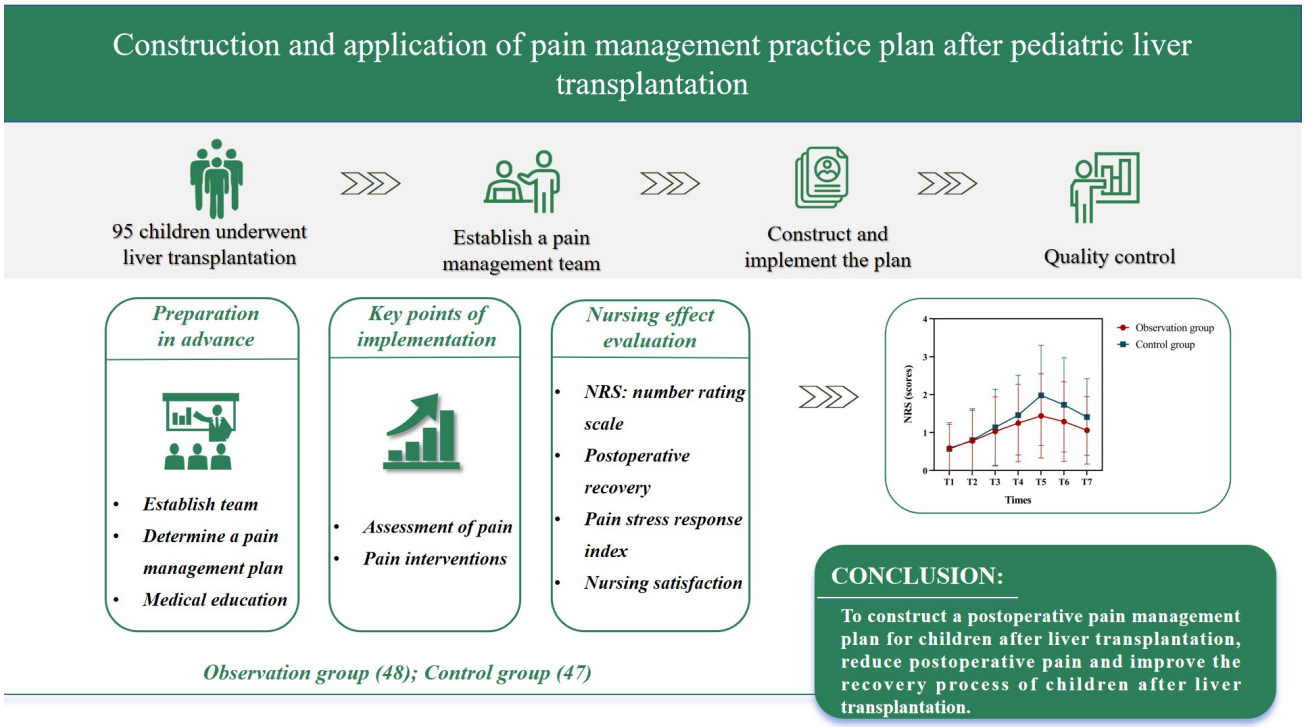
Compared with that in adults, pain assessment and treatment in children are more challenging, which substantially increases the difficulty of postoperative pain control in pediatric patients [4]. Additionally, potential ischemia-reperfusion injury to the transplanted liver may impair hepatic metabolic function, alter drug pharmacokinetics and pharmacodynamics, reduce drug-binding protein concentrations, and cause abnormal drug volume distribution. These changes may further compromise the effectiveness of analgesics and aggravate postoperative pain [5].

Pain, as a negative feeling and emotional experience, can lead to various negative sequelae. When pain in children is not adequately treated, corresponding hormones and endogenous neuropeptides are released, which are involved in pain regulation, catabolism, immunosuppression, postoperative pharmacokinetic changes secondary to transplant surgery, and hemodynamic stability. Thus, insufficient postoperative pain control adversely affects children's physiological, metabolic, and psychological states [6]. Persistent pain may also intensify the surgical stress response and contribute to organ dysfunction, thereby prolonging recovery. Despite this, evidence shows that pediatric pain is undertreated in most clinical settings [7].



Graphical Abstract.

Opioid-based analgesia, including morphine and fentanyl, currently remains the most commonly used approach in clinical practice. However, for pain management in children following liver transplantation, no standardized management plan exists. Therefore, in this study, we aimed to develop a structured postoperative pain management program for pediatric liver transplantation to improve pain assessment and nursing care, ultimately promoting postoperative recovery and improving overall prognosis in pediatric patients.

Methods

Research Participants

This study was a retrospective analysis of 95 children who underwent liver transplantation at The Third Affiliated Hospital of Sun Yat-sen University between May 2020 and May 2025 and were admitted postoperatively. Among them, 47 children admitted to the hospital between May 2020 and May 2022 received a conventional pain management plan and were assigned to the control group. Conversely, 48 children admitted between June 2022 and May 2025 received an multimodal analgesia program and were assigned to the observation group.

Inclusion criteria were as follows: (1) age >8 years and ≤14 years; (2) first-time liver transplantation; (3) essentially normal heart, lung, and kidney functions; and (4) written informed consent provided by the patients' legal guardians.

Exclusion criteria were as follows: (1) age ≤8 years or >14 years; (2) severe cardiopulmonary insufficiency; and (3) liver transplantation combined with transplantation of other organs.

Observation Group Pain Management Plan

Preparation for Pain Management

First, a multidisciplinary pain nursing management team comprising nine members was established following pediatric liver transplantation. The team leaders included one director each from the nursing and transplantation departments, who were responsible for developing, supervising, and guiding the project activity plan. A standardized pain assessment system, along with relevant rules and regulations, was established, and the pain nursing workflow was revised. Through hierarchical, standardized, theoretical, and skills-based training and assessment, a safety prevention system for pain intervention was constructed, and pain assessment management indicators were formulated. Five senior nurses were responsible for ward-level pain management, including documentation, supervision, and handover of pain assessment and treatment. The remaining two members were graduate nursing students responsible for data collection and organization.

Second, through a comprehensive literature review, the team identified and adopted appropriate pediatric pain assessment tools. General patient information, including admission number, sex, diagnosis, admission time, injury time, operation time, and primary accompanying relationship, was recorded. Pain assessment and management information included pain scores, concomitant pain state, vital signs during pain episodes, and intervention measures.

Adverse reactions monitored included gastrointestinal reactions, incision bleeding, urinary retention, restlessness, respiratory depression, and incision infection. The team leaders also established pain management policies, including pain nursing management, pain nursing assessments, and pain patient education systems. The pain management workflow was revised to clearly define the assessment timing, frequency, content, and documentation requirements, providing nurses with guidance for implementation and promoting standardized and systematic pain nursing management.

Lastly, upon transfer of a patient from the intensive care unit (ICU) to the general ward, the responsible ward nurse provided pain management-related education to the patient's parents or guardians. The nurse first explained the importance of effective pain management and highlighted key points requiring attention. Subsequently, the nurse described common pain-related symptoms the patient might experience and the corresponding measures that medical staff may implement during pain management, ensuring that parents fully understand the process. Educational strategies included interactive instruction using PowerPoint (version 2016, Microsoft Corporation, Redmond, WA, USA) presentations, animation clips, and pain assessment forms. Parents' understanding of pain management was assessed to improve compliance and cooperation during postoperative care.

Implementation Points of Pain Management

(1) Pain assessment: the Numerical Rating Scale (NRS) was used to assess pain intensity [8]. The NRS consists of 11 points ranging from 0 to 10, where 0 indicates no pain, and 10 indicates the most severe pain imaginable. Children were asked to report the number that best represented their pain intensity, with higher scores indicating greater pain intensity. Pain intensity was categorized as follows: no pain (NRS=0), mild pain (NRS=1–3), moderate pain (NRS=4–6), and severe pain (NRS=7–10).

(2) Pain management: nursing staff actively communicated with children using a kind, gentle, and patient approach to facilitate cooperation during pain assessment. A multimodal analgesia program was implemented, combining non-pharmacological interventions (music therapy, touch nursing, and distraction games) and individualized drug analgesia. Pain was assessed on the day of surgery (T1), the morning of postoperative day 1 (T2), the afternoon of postoperative day 1 (T3), the morning of postoperative day 2 (T4), the afternoon of postoperative day 2 (T5), the morning of postoperative day 3 (T6), and the afternoon of postoperative day 3 (T7).

For children with pain scores <4, non-drug interventions were prioritized according to individual interests, such as playing games, reading picture books, watching television, listening to children's songs, or playing with toys, to shift the child's attention and improve pain tolerance. The specific measures are shown in Table 1. Additional measures, such as gentle stroking and deep-breathing exercises, were also employed to reduce pain.

For children with pain scores ≥ 4, ibuprofen or other drugs were selected in accordance with the doctor's advice in combination with non-drug interventions. Oral ibuprofen suspension was the preferred first-line medication, administered at 5–10 mg/kg per dose every 6–8 h, depending on pain severity, with a maximum of four doses within 24 h. Following medication administration, nursing staff increased monitoring frequency, reassessed changes in pain symptoms, and closely observed for adverse reactions, including respiratory depression, to ensure the timely diagnosis, symptomatic treatment, and documentation of such reactions.

Furthermore, nurses assessed children's psychological status, addressed children's negative emotions related to pain or temporary activity limitations, and communicated patiently, tailoring their approach to each child's communication ability. Once clinically stable, children were encouraged to engage in appropriate, enjoyable activities that did not interfere with postoperative rehabilitation to help regulate their emotional state.

Quality Control of Management

The children's pain management quality was continuously supervised, with timely communication of information and feedback to ensure accuracy and effectiveness. Through targeted audits of nursing documentation and real-time data extraction from electronic medical records, core indicators, including pain assessment completeness, timeliness of intervention implementation, and satisfaction of children and their families, were analyzed. A three-level feedback mechanism was established: primary nurses reviewed representative cases daily, and head nurses conducted weekly quality analyses. Comprehensive monitoring and feedback mechanisms were established across all aspects of pain management, accompanied by regular training, on-site supervision, performance assessment, and follow-up observation of medical staff. Prospective risk identification was applied to anticipate possible issues, thereby supporting continuous pain quality management. Additionally, the nursing department conducted monthly interdisciplinary discussions and performed root cause analyses of identified problems, such as poor analgesic effects and unplanned extubation, to continuously optimize the nursing process.

Pain Management Plan for the Control Group

The control group underwent pain assessments at the same time points as the observation group (T1–T7). Based on the assessment results, standard pain management measures were implemented, including psychological intervention, physical pain relief measures, oral analgesics, and intravenous analgesic pump therapy, as appropriate. The children's pain relief status was reassessed and documented

Table 1. Standardized non-pharmacological pain management process.

Module	Core strategy	Specific operation procedures and standards
Pacify	Therapeutic touch	1. Environment preparation: ensure the environment is warm and private. 2. Operator's preparation: warm hands and gently inform the child. 3. Standard technique: use a slow and gentle touch, and stroke the child's back, arms, or hands in one direction for 5–15 min. 4. Observation: pay close attention to the facial expressions and the degree of relaxation of the child's limbs.
Divert	Divert attention	1. Assessing interests: quickly inquire or observe the child's preferences (such as cartoon characters, game types). 2. Offer options: provide two to three age-appropriate choices (e.g., "Do you want to watch Peppa Pig cartoon or play with this toy car?"). 3. Immersive interaction: start the interaction 1–2 min before performing painful procedures (such as dressing changes), and maintain the interaction throughout the process.
Engage	Gamification participation	1. Scenario reconstruction: transform the medical process into a game (for example: weighing oneself is "launching a rocket", listening to the patient's heart is "listening to the sound of a little train"). 2. Give a sense of control: allow the child to hold or operate non-medical toys or picture books. 3. Breathing game: transform the guidance on deep breathing into a "feather blowing competition" or a "bubble blowing game".
Soothe	Multisensory relaxation	1. Auditory: play pre-set, soothing children's songs or natural sounds (such as rain sounds, stream sounds), with the volume controlled below 40 decibels. 2. Visual: offer picture books or animations with soft colors and simple scenes. 3. Tactile sensory: provide soothing towels, soft dolls, and other safe and clean tactile toys for them to hold and embrace.

30 min post-intervention, adverse reactions were monitored for, and pain-related health education was provided to the children's guardians and recorded.

At T1 and T7, peripheral venous blood samples were collected from the children. Prostaglandin E_2 (PGE_2) levels were measured using radioimmunoassay, norepinephrine (NE) and epinephrine (E) levels were detected using enzyme-linked immunosorbent assays, and dopamine (DA) levels were assessed using an immunoluminescence assay.

Observation Indicators

Primary outcome: pain intensity was assessed at seven time points (T1–T7) using the NRS. Secondary outcomes: (1) Postoperative recovery indicators: time to first flatus, time to ambulation, time to first bowel movement, time to first oral feeding, and length of hospital stay. (2) Pain-related stress response indicators: prostaglandin E_2 (PGE_2), dopamine (DA), epinephrine (E), and norepinephrine (NE). (3) Adverse reactions: gastrointestinal reactions, incision bleeding, urinary retention, restlessness, respiratory depression, and incision infection. Other outcome: family satisfaction with nursing care.

Family members' satisfaction with nursing care was assessed using a self-designed nursing satisfaction questionnaire, which showed good internal consistency (Cronbach's $\alpha = 0.91$). The questionnaire included four domains: nursing service attitude, nursing operation, nursing rounds, and health education provided during transfer from the ICU. The questionnaire is scored out of 100 points. A total score $\geq$80 points is classified as "satisfied", a total score $\geq$60 points and $<$80 points is classified as "basically satisfied", and a total score $<$60 points is classified as "dissatisfied". This assignment and classification are determined in combination with the clinical evaluation practices and the nursing assessment requirements of The Third Affiliated Hospital of Sun Yat-sen University.

Statistical Analysis

All scale data were entered into a computerized database for score conversion and analyzed using SPSS (version 26.0, IBM SPSS). Continuous variables were tested for normality using the Shapiro–Wilk test. Normally distributed data are expressed as mean $\pm$ standard deviation, while non-normally distributed continuous variables are presented as median and interquartile range. Categorical variables are expressed as frequencies and percentages.

Between-group comparisons for normally distributed continuous variables with homogeneous variances were performed using independent sample *t*-tests. Using the Mann-Whitney U test to compare the pain scores between groups at each time point. Given the exploratory nature of the repeated time point comparisons, these analyses are regarded as descriptive analyses. For categorical variables, for a 2 $\times$ 2 contingency table, if the total number of cases N is

Table 2. Baseline data.

Item	Observation group (n = 48)	Control group (n = 47)	χ^2/Z	*p*
Sex				
Female	27 (56.25%)	25 (53.19%)	0.090	0.765
Male	21 (43.75%)	22 (46.81%)		
Age (years)	11 (9, 12)	11 (10, 12)	1.474	0.141
The place of residence				
City	22 (45.83%)	24 (51.06%)	0.260	0.610
Rural areas	26 (54.17%)	23 (48.94%)		
Parents' educational level				
College degree or above	24 (50.00%)	22 (46.81%)	0.097	0.756
Below a college degree	24 (50.00%)	25 (53.19%)		
Monthly household income (yuan)				
≥6000	40 (83.33%)	38 (80.85%)	0.100	0.752
<6000	8 (16.67%)	9 (19.15%)		
Surgical method				
Donor liver transplantation	38 (79.17%)	38 (80.85%)		
Split liver transplantation	7 (14.58%)	7 (14.89%)	0.189	0.910
Domino liver transplantation	3 (6.25%)	2 (4.26%)		

1 yuan = 0.1471 dollar

Table 3. Comparison of pain levels between the two groups over time.

Item	T1	T2	T3	T4	T5	T6	T7
Observation group (n = 48)	0 (0, 1)	1 (0, 1)	0 (0, 1)	0 (0, 1)	1 (0, 1)	1 (0, 1)	1 (0, 1)
Control group (n = 47)	0 (0, 1)	1 (0, 1)	1 (1, 2)	1 (1, 3)	2 (1, 3)	2 (1, 3)	2 (1, 2)
Z	0.476	0.126	2.375	2.548	3.862	4.324	3.970
p	0.621	0.983	0.038	0.015	0.010	0.000	0.005

≥40 and all theoretical frequencies are ≥5, the Pearson chi-square test should be used; if N is greater than or equal to 40 but there is a theoretical frequency where $1 \leq T < 5$, a continuity-corrected chi-square test is employed; if N is less than 40 or the theoretical frequency T is less than 1, then the Fisher exact test should be used. For R×C contingency tables (where either the rows or columns are greater than 2), if the number of cells with theoretical frequencies less than 5 does not exceed 20% of the total number of cells, and there are no theoretical frequencies less than 1, the Pearson chi-square test is used; otherwise, the Fisher exact test is employed (calculated through the Monte Carlo simulation method). A two-side $p < 0.05$ was considered statistically significant.

Results

Baseline Data

No significant between-group differences were observed regarding age, sex, place of residence, parents' educational level, monthly household income, or surgical method ($p > 0.05$), indicating that the groups were well-balanced and comparable (Table 2).

Comparison of Pain Levels Between the Two Groups

Overall pain levels in both groups initially increased and then gradually decreased over time. Specifically, there was no significant between-group difference in pain scores at T1 and T2 ($p > 0.05$); however, pain scores at T3–T7 were significantly lower in the observation group than those in the control group ($p < 0.05$) (Table 3, Fig. 1).

Comparison of Postoperative Recovery

Children in the observation group achieved earlier postoperative ambulation and had shorter hospital stays than did those in the control group ($p < 0.05$). However, no significant differences were found between the groups in times to first flatus, defecation, or feeding ($p > 0.05$) (Table 4).

Comparison of Postoperative Pain Stress Response Indicators and Adverse Reactions

Chi-square analysis showed a significant difference in adverse reactions between the two groups, only for restlessness ($p < 0.05$) (Table 5). There was no statistically significant difference in pain-related stress response indicators between the two groups at T1 ($p > 0.05$). At T7, a significant difference in PGE_2, DA, E, and NE levels was observed, with lower levels observed in the observation group than those in the control group ($p < 0.05$) (Table 6, Fig. 2).

Comparison of Family Satisfaction With Nursing Care

An anonymous nursing satisfaction survey was administered to the children's family members at the time of

Table 4. Comparison of postoperative recovery.

Item	First exhaust time (h)	Time to ambulation (h)	First bowel movement (h)	Meal time (h)	Hospitalization duration (days)
Observation group (n = 48)	23.4 ± 7.8	19.4 ± 8.3	37.5 ± 7.5	27.8 ± 7.6	21.3 ± 7.4
Control group (n = 47)	25.8 ± 8.1	24.5 ± 7.4	38.9 ± 8.1	28.8 ± 8.7	25.6 ± 6.7
t	1.471	3.159	0.874	0.597	2.967
p	0.145	0.002	0.384	0.552	0.004

Table 5. Comparison of adverse reactions between the two groups of children.

Item	Gastrointestinal reactions	Incision bleeding	Urinary retention	Restlessness	Respiratory depression	Incision infection
Observation group (n = 48)	16 (33.3)	0 (0.0)	2 (4.2)	6 (12.5)	3 (6.3)	0 (0.0)
Control group (n = 47)	17 (36.2)	1 (2.1)	2 (4.3)	14 (29.8)	3 (6.4)	0 (0.0)
χ^2/Fisher	0.084	-	0.000	4.270	0.000	-
p	0.772	0.495	1.000	0.039	1.000	-

-, indicates that Fisher's exact test was used and no test statistic was reported.

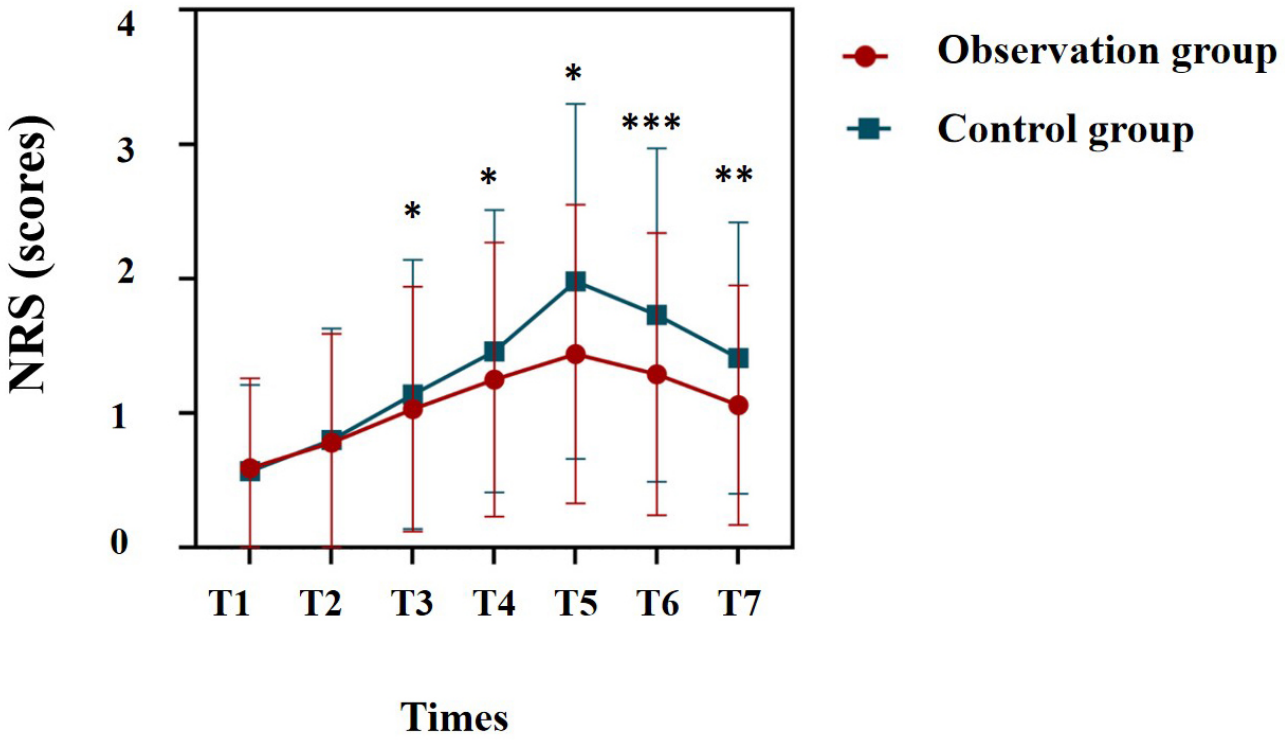


Fig. 1. Changes in pain level scores over time in the two groups. For the purpose of visualization, this is presented as mean ± standard deviation, and non-parametric methods were used for statistical comparisons. * indicates $p < 0.05$ between the two groups, ** indicates $p < 0.01$ between the two groups, and *** indicates $p < 0.001$ between the two groups. NRS, Numerical Rating Scale.

transfer from the ICU. There was no statistically significant between-group difference in satisfaction with nursing service attitude or operations ($p > 0.05$). However, regarding nursing rounds and health education, there were significant differences in the distribution of responses—specifically "satisfied", "basically satisfied", and "dissatisfied"—between the two groups ($p < 0.05$ for both items) (Table 7).

Discussion

Liver transplantation is currently the standard treatment for children with end-stage liver disease [9]. Postoperative pain management is a core issue in perioperative treatment and recovery in pediatric liver transplantation. Continuous advancement in liver transplantation techniques has led to significantly improved postoperative survival rates of children; however, effective postoperative pain management remains a significant clinical challenge. Owing to children's unique physiology, psychology, and behavioral ex-

Table 6. Comparison of postoperative pain stress response indicators between the two groups of children.

Item	PGE_2 (ng/mL)		DA (ng/mL)		E (nmol/L)		NE (nmol/L)	
	T1	T7	T1	T7	T1	T7	T1	T7
Observation group (n = 48)	353.75 ± 39.24	322.27 ± 40.24	25.37 ± 5.53	21.34 ± 5.13	0.94 ± 0.27	0.43 ± 0.13	1.78 ± 0.61	1.21 ± 0.43
Control group (n = 47)	342.64 ± 36.82	358.64 ± 41.47	26.85 ± 5.53	24.02 ± 4.74	0.92 ± 0.25	0.71 ± 0.16	1.81 ± 0.58	1.63 ± 0.54
t	1.422	4.338	1.304	2.643	0.374	9.371	0.246	4.198
p	0.158	<0.001	0.195	0.010	0.709	<0.001	0.807	<0.001

PGE_2, prostaglandin E_2; DA, dopamine; E, epinephrine; NE, norepinephrine.

Table 7. Comparison of family satisfaction with nursing care.

Item	Service attitude			Nursing operations		
	Satisfied	Basically satisfied	Dissatisfied	Satisfied	Basically satisfied	Dissatisfied
Observation group (n = 48)	42	5	1	41	6	1
Control group (n = 47)	38	8	1	39	6	2
χ^2		1.115			0.493	
p		0.690			0.907	
Item	Nursing patrol			Health education		
	Satisfied	Basically satisfied	Dissatisfied	Satisfied	Basically satisfied	Dissatisfied
Observation group (n = 48)	46	2	0	47	0	1
Control group (n = 47)	37	7	3	38	7	2
χ^2		6.226			8.652	
p		0.030			0.005	

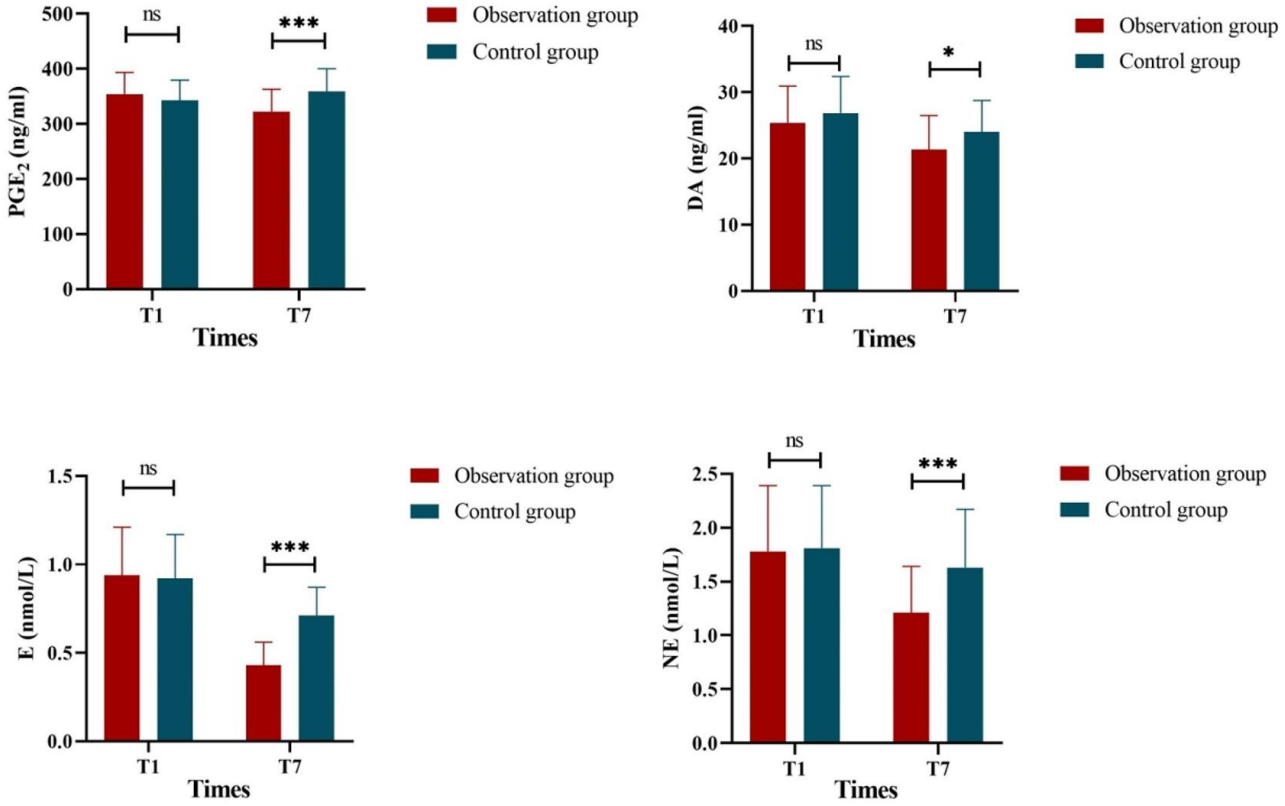


Fig. 2. Comparison of postoperative pain stress response indicators between the two groups of children. * indicates $p < 0.05$ between the two groups, and *** indicates $p < 0.001$ between the two groups. ns indicates $p > 0.05$ between the two groups. PGE_2, prostaglandin E_2; DA, dopamine; E, epinephrine; NE, norepinephrine.

pression, the identification and management of postoperative pain are often more complex than in adults. Inadequate pain management not only affects postoperative comfort and compliance of children but also has a profound impact on their immune function, recovery speed, and overall prognosis [10]. In the present study, the implementation of a structured pain management program for children after liver transplantation, combining multiple pain assessment tools and intervention methods, yielded favorable outcomes and helped standardize pain management in pediatric liver transplantation.

Accurate pain assessment is a prerequisite and the foundation for effective pain management. Children's pain expression is influenced by their age, cognitive ability, and cultural background, making pain assessment more complex than in adults [11]. In this study, the NRS was adopted as the primary pain assessment tool, with flexible application based on the child's age and language proficiency. This diverse assessment approach improved pain assessment accuracy and increased family member compliance. Nevertheless, although the NRS is simple and easy to implement, it may be less suitable for younger children or those with language expression difficulties. Therefore, in future research, more detailed and personalized assessment tools, such as a comprehensive assessment approach that combines behavioral performance with physiological signals, should be explored.

The pain management program employed in this study integrated two major categories of measures, drug and non-drug interventions, implemented within a multimodal analgesia framework. Multimodal analgesia strategies have been widely recognized as an effective strategy for relieving postoperative pain, reducing dependence on single-agent analgesics, and minimizing adverse effects [12]. Pharmacological interventions used included non-steroidal anti-inflammatory drugs (such as ibuprofen), while non-pharmacological interventions encompassed music therapy, touch care, and distraction games. The findings showed significantly lower pain scores in the observation group than those in the control group after multimodal analgesia was implemented, indicating that multimodal analgesia can better relieve postoperative pain. Additionally, non-pharmacological interventions also played an important supportive role during the pain management process: by establishing a good communication relationship with the child patient and comforting them with kind words and behaviors, not only was the child's pain alleviated, but their anxiety was also reduced [13]. Currently, given their safety and feasibility, non-pharmacological interventions have considerable potential as adjuncts to pharmacological analgesia, particularly after complex procedures such as pediatric liver transplantation.

Family involvement is a critical component in postoperative pain management. In this study, nursing staff provided structured pain management education to family members, enabling them to better understand, support, and participate in pain management in the pediatric patients [14]. Family members not only actively contributed to postoperative pain assessment but also enhanced their knowledge of pain management, enabling them to identify children's pain in a timely and effective manner, thereby improving the overall treatment effect. The significantly higher satisfaction with nursing rounds and health education observed in the observation group than that in the control group indicates a significant correlation between the family members' recognition of nursing quality and the effect of pain management. However, the cognitive differences among family members regarding analgesic drugs also require considerable attention. A study has reported that some family members may be concerned about opioid drugs, which may affect compliance with drug use [15]. Therefore, when conducting pain management, nursing staff should provide detailed explanations based on the cognitive level of family members to reduce unnecessary anxiety and misunderstanding and ensure the smooth progress of pain relief treatment.

In the present study, to ensure effective implementation of the pain management system, we incorporated quality control and feedback mechanisms throughout the pain management process. By monitoring key indicators, such as the completeness rate of pain assessment, timeliness and appropriateness of intervention implementation, and family satisfaction, the standardization and accuracy of each component were ensured. Furthermore, regular training of nursing staff and onsite supervision facilitated the timely identification of problems and the implementation of corresponding improvement measures, thereby continuously enhancing pain management quality. Nevertheless, despite the establishment of an effective quality control system, some challenges remained in pain management implementation. For instance, some caregivers may have been constrained by time and workload during actual operations, thereby affecting the timeliness of pain assessment and intervention. Therefore, further studies are necessary to optimize the pain management process, enhance the professional skills and work efficiency of nursing staff, and ensure that each pediatric patient's pain is managed in a timely and effective manner.

Evaluation of postoperative recovery indicators revealed noteworthy findings. As shown in Table 3, no significant differences were observed between the two groups in measures reflecting early gastrointestinal function recovery, including time to flatus, defecation, and oral feeding. This suggests that the pain management protocol did not directly accelerate gastrointestinal motility. However, its beneficial effects on clinical recovery were evident in two areas: earlier ambulation and a shorter postoperative hospital stay. We speculate that the primary contribution of optimized pain control is the effective relief of postoperative discomfort, thereby enhancing children's willingness and ability to move. Early ambulation is an important rehabilitation index, as it helps prevent complications, improve cardiopulmonary function, and may indirectly promote re-

covery by optimizing the overall physiological status, ultimately contributing to a shorter hospital stay [16,17]. It is important to note that postoperative recovery is multifactorial; in addition to pain management, subtle differences in surgical techniques, details of anesthesia protocols, perioperative fluid management strategies, and many other factors may also influence outcomes. Therefore, the results of this study should be interpreted to suggest that optimized pain management primarily reduces hospital length of stay by improving mobility and promoting overall rehabilitation, rather than exerting a direct, independent acceleration effect on gastrointestinal function. Overall, the pain management program developed in this study effectively alleviated postoperative pain in children following liver transplantation by applying multimodal analgesia, shortened recovery time, and had a positive impact on both physical and psychological well-being.

However, this study has some limitations. First, owing to its retrospective, non-randomized design, patient grouping was based on the evolution of clinical practice protocols over time, rather than through random allocation. While baseline characteristics were comparable across groups, the influence of unmeasured confounding factors cannot be entirely excluded. In future studies, subgroup analyses or more refined longitudinal research designs can be employed to help control for time-related confounding factors. Second, as this was a single-center study, the generalizability of the findings requires validation in larger, multicenter studies involving transplant centers with different scales and treatment protocols. Moreover, retrospective data collection may be limited by the completeness and accuracy of medical records. Therefore, well-designed multicenter prospective randomized controlled trials are warranted to further explore and improve this pain management program.

Conclusions

The postoperative pain management program for pediatric liver transplantation effectively alleviated postoperative pain through multimodal analgesia, shortened recovery time, and improved family satisfaction. This approach shows good clinical value and provides a practical reference for standardizing postoperative pain management in pediatric liver transplantation.

Availability of Data and Materials

The data are not publicly available due to privacy and ethical restrictions, but are available from the corresponding author upon reasonable request.

Author Contributions

JFZ: conceptualization, methodology, investigation, formal analysis, data curation, and writing - original draft. HYZ: validation, resources, software, visualization, conceptualization, study design, experiment conduction, and writing - review & editing. XLZ: conceptualization, study design, data acquisition and analysis, supervision, project administration, and writing - review & editing. All authors have been involved in revising the manuscript critically for important intellectual content. All authors gave final approval of the version to be published. All authors have participated sufficiently in the work to take public responsibility for appropriate portions of the content and agreed to be accountable for all aspects of the work in ensuring that questions related to its accuracy or integrity.

Ethics Approval and Consent to Participate

This study was conducted in accordance with the Declaration of Helsinki, and ethical principles for medical, psychological, and sociological research involving human participants. The Ethics Committee of The Third Affiliated Hospital of Sun Yat-sen University approved the study protocol (NO. II2025-411-01). All patients' legal guardians signed the informed consent in this study.

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Conflict of Interest

The authors declare no conflict of interest.

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