

Original Article

Application of goal-directed quantitative activity management based on wearable technology in children with appendicitis: a retrospective cohort study

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Abstract: Objective: To evaluate the effectiveness of wearable technology-based, goal-directed quantitative activity management on postoperative recovery in pediatric appendectomy patients using a retrospective cohort design. Methods: A total of 150 pediatric appendectomy patients (July 2024-March 2025) were retrospectively divided into three groups (n = 50 each): Group 1 (conventional care), Group 2 (goal-directed quantitative activity management), and Group 3 (wearable device-assisted goal-directed management). Daily walking distance, time to first ambulation, time to first flatus, length of hospital stay, adverse events, and patient satisfaction were compared. Results: The three groups differed in mean age (P = 0.020); age was therefore adjusted for in all multivariable analyses. Postoperative day 3 walking distances were 979.75 ± 149.42 m (Group 1), $1,433.84 \pm 162.63$ m (Group 2), and $1,741.21 \pm 178.30$ m (Group 3) (P < 0.001). Time to first ambulation (18.09 ± 5.02 h vs. 15.13 ± 2.60 h vs. 9.52 ± 2.39 h) and time to first flatus (23.28 ± 5.45 h vs. 17.65 ± 3.71 h vs. 13.17 ± 4.28 h) differed significantly (both P < 0.001). Length of hospital stay decreased from 8.29 ± 1.54 days (Group 1) to 5.60 ± 0.98 days (Group 2) and 4.28 ± 0.58 days (Group 3) (P < 0.001). Adverse event incidence was 30.0% (Group 1), 24.0% (Group 2), and 6.0% (Group 3) (P = 0.008). Satisfaction scores were highest in Group 3 (98.32 ± 1.28), followed by Group 2 (95.26 ± 1.30) and Group 1 (91.59 ± 3.34) (P < 0.001). Conclusions: Wearable device-assisted, goal-directed quantitative activity management significantly accelerates postoperative recovery, reduces complications, shortens hospital stay by over four days compared to conventional care, and improves patient and family satisfaction in pediatric appendicitis.

Keywords: Pediatric appendicitis, wearable devices, goal-directed activity management, postoperative recovery, retrospective cohort study

Introduction

Acute appendicitis is one of the most common acute surgical abdominal incidences in childhood. Epidemiological data show that it accounts for approximately 7%-8% of pediatric acute abdominal pain cases [1]. Laparoscopic appendectomy has become the standard surgical procedure for pediatric appendicitis due to its advantages of minimal invasiveness, less postoperative pain, and rapid recovery. However, postoperative rehabilitation management still faces many challenges. Long-term bed rest after surgery can lead to a series of problems such as weakened intestinal peristalsis, abdominal muscle relaxation, and difficulty in expectorating respiratory secretions, significantly

increasing the risk of complications such as intestinal obstruction, intra-abdominal adhesion, atelectasis, and pulmonary infection. Literature reports the incidence of postoperative complications after pediatric appendectomy is as high as 10%-20% [2, 3]. Therefore, how to optimize postoperative rehabilitation management, accelerate functional recovery, and reduce the occurrence of complications has always been a focus and difficulty in pediatric surgical clinical practice.

The proposal of the concept of Enhanced Recovery After Surgery (ERAS) has provided new ideas for postoperative management. As one of the core elements of the ERAS program, early ambulation has been proven in the field of adult

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surgery to effectively promote the recovery of gastrointestinal function, reduce postoperative complications, shorten the length of hospital stay, and improve patient prognosis [4, 5]. However, the promotion and application of this concept in pediatric patients have progressed slowly. Children are not simply miniature adults; they have uniqueness in physiology, psychology, and social support: lower postoperative pain thresholds, more prominent fear and anxiety, poor adaptability to unfamiliar environments, and the traditional concept of “postoperative convalescence” generally held by caregivers, resulting in generally low acceptance and compliance of children to early ambulation [6, 7]. Clinical observations show that most children tend to stay in bed for a long time after surgery due to fear of pain or fatigue. Even when they get out of bed, their activity is often insufficient, short in duration, and random, making it difficult to achieve the purpose of effective rehabilitation.

On the other hand, there is currently a lack of unified standards and quantitative basis for postoperative activity guidance in children. In clinical practice, medical staff mostly give general advice to “move more” based on personal experience, lacking personalized activity programs for children of different age stages and different disease severities. Key parameters such as activity intensity, duration, and frequency are not clearly defined, making it difficult to evaluate and compare the effect of rehabilitation. This experience-oriented management model not only limits the application of the ERAS concept in the pediatric field but also results in uneven quality of postoperative rehabilitation, objectively hindering the refined development of perioperative management in pediatric surgery [8, 9].

In recent years, the rapid development of wearable sensing technology has provided new technical means to solve the above problems. Wearable devices such as smart bracelets and activity trackers can monitor multiple physiological and behavioral parameters in real-time, continuously, and non-invasively, including step count, walking distance, heart rate, respiratory rate, sleep staging, heart rate variability (HRV), and blood oxygen saturation [1, 10]. These objective data can not only be used to quantify and evaluate patients' daily activity levels but

also reflect the state of autonomic nerve function, sleep quality, and physiological rhythm characteristics. Recent studies have shown that biological rhythm indicators extracted from wearable devices, such as circadian rhythm stability and diurnal variation patterns of HRV, can early predict the occurrence of postoperative complications in children, with a sensitivity of up to 90%, providing a valuable early warning window for clinical intervention [11, 12]. In addition, the study by de Kwasnicki et al. [13] confirmed that step monitoring can be used as an objective measure of functional recovery after pediatric appendectomy, and the step recovery trajectory is significantly related to the length of hospital stay. Leenen, et al. [14] further reported that integrating pedometers into ERAS programs can significantly shorten the hospital stay of patients undergoing colorectal surgery by promoting quantifiable, data-driven ambulation. These studies suggest that wearable devices can not only be used for activity monitoring but also have the potential to become an important bridge connecting objective physiological indicators and clinical outcomes.

With the above background, this study, based on relevant literature at home and abroad and combined with the physiological and psychological characteristics of children and clinical reality, designed a phased, goal-directed quantitative activity management program integrating wearable device monitoring. The core content of the program includes: (1) Formulating stratified and progressive daily activity goals according to the age of the child (preschool, school-age, adolescent) to achieve individualized adjustment of activity intensity; (2) Using smart wristbands to monitor parameters such as activity, heart rate, and sleep in real-time to dynamically assess the child's tolerance and adjust goals in time; (3) Establishing a “medical staff-child-parent” interactive feedback mechanism based on a mobile application, transforming passive rehabilitation into an active participation process through WeChat group check-ins, real-time data sharing, and phased rewards; (4) Pre-setting safety thresholds to automatically trigger warnings when abnormal physiological parameters (such as persistent increase in heart rate, decrease in blood oxygen saturation) occur, ensuring the safety of the rehabilitation process.

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This study employed a retrospective cohort design to collect clinical data of pediatric patients who underwent laparoscopic appendectomy at Anhui Children's Hospital between July 2024 and March 2025 via the hospital's electronic medical record system and the wearable device database. According to the actual postoperative management methods received, the patients were divided into a conventional care group, a goal-directed activity management group, and a wearable device-assisted goal-directed activity management group. The primary objective of the study was to compare the differences in postoperative activity levels, time to first ambulation, gastrointestinal function recovery time, length of hospital stay, incidence of adverse events, and patient satisfaction among the three groups to evaluate the effectiveness of the wearable device-assisted management model. The secondary objectives included: (1) analyzing the associations between wearable-derived indicators (such as sleep efficiency, HRV, and circadian rhythm amplitude) and clinical outcomes (length of hospital stay, complications); (2) exploring the correlation between pain scores and sleep efficiency; and (3) conducting an exploratory analysis of candidate wearable-derived features potentially associated with complication risk, using data from Group 3 to assess the early warning potential of wearable data. Through the above analyses, this study aims to provide evidence-based indications for the optimization of postoperative rehabilitation management in children and promote the transformation of pediatric perioperative care from an experience-oriented to a data-driven precision model.

Materials and methods

Study design and ethical considerations

This study is a single-center retrospective cohort study conducted at Anhui Children's Hospital. Clinical data of pediatric patients who underwent appendectomy at our hospital between July 2024 and March 2025 were retrospectively collected. The study protocol was approved by the Ethics Committee of Anhui Children's Hospital. All procedures performed in this study involving human participants were in accordance with the Declaration of Helsinki (as revised in 2013).

According to the postoperative management they received, patients were divided into three groups: Group 1 (Conventional Care Group), Group 2 (Goal-Directed Quantitative Activity Management Group), and Group 3 (Wearable Device-Assisted Goal-Directed Quantitative Activity Management Group), with 50 patients in each group. Outcome assessors were blinded to the group assignments to minimize detection bias. A flowchart was used to ensure transparency regarding participant selection, grouping, follow-up, and analysis (**Figure 1**).

Study participants

Pediatric patients meeting the following criteria were screened through the hospital information system: (1) aged 3-18 years; (2) diagnosed with simple or suppurative appendicitis via pre-operative ultrasound or computed tomography (CT) and underwent laparoscopic appendectomy; (3) for Group 3, patients were required to wear a smart activity tracker postoperatively and complete relevant data recording. Exclusion criteria were: (1) congenital intestinal malformations or immunodeficiency diseases; (2) perforated appendicitis or conversion to open surgery during the operation; (3) incomplete clinical data or missing key outcome data.

Baseline characteristics of all included patients were extracted from electronic medical records, including age, sex, body mass index (BMI), guardian relationship (parent/grandparent), time from symptom onset to hospital admission (< 24 h, 24-48 h, 48-72 h), appendicitis type (simple/suppurative), and weight status (normal/overweight/obese). Data were collected using a structured data collection form, and multiple imputation was employed to handle a small number of missing values.

Extraction of intervention data

Postoperative management protocols actually received by patients in each group were extracted from nursing records and medical orders, detailed as follows:

Group 1 (conventional care group): Medical records indicate that patients in this group remained on strict bed rest for the first 6 hours postoperatively, during which vital signs (heart rate, blood pressure, respiratory rate, and oxygen saturation) were continuously monitored.

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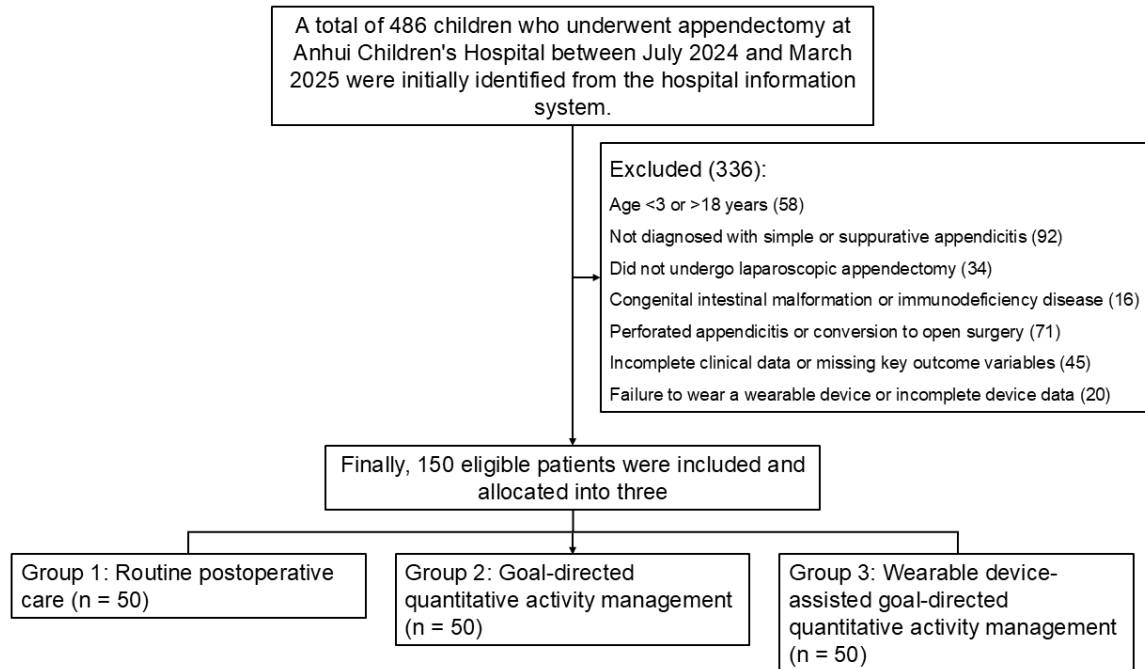


Figure 1. Study flow diagram.

After 6 hours, nurses assisted patients in sitting at the bedside, and caregivers were instructed to gradually support them in walking within the ward corridor, to the extent that the patient felt no discomfort. Activities that increased intra-abdominal pressure, such as running, jumping, or lifting heavy objects, were prohibited. Caregivers recorded daily walking distance using corridor markers, and the data were documented in the nursing record sheet.

Caregiver education (Groups 2 and 3): Prior to the initiation of postoperative ambulation protocols, all caregivers of children in Groups 2 and 3 received standardized preoperative education delivered by a dedicated research nurse. The education session, supplemented by a printed illustrated guide, covered the principles of Enhanced Recovery After Surgery, the physiological benefits of early mobilization in children, and practical strategies to encourage activity while managing postoperative discomfort. This standardized training aimed to ensure consistent caregiver support across both intervention groups. Walking distance was recorded daily by caregivers using corridor markers and verified by nursing staff, with data transcribed into the nursing record sheet.

Group 2 (goal-directed quantitative activity management group): Medical records show that

this group received a phased, quantitative early ambulation protocol. The protocol was implemented by a project team (including a chief physician, associate chief nurses, deputy head nurse, research nurses, attending physicians, and head nurse) and included a daily activity schedule, age-stratified goals (preschool, school-age, adolescent), and psychological reinforcement strategies (such as verbal praise and step challenges). Daily activity goals were dynamically adjusted according to patient tolerance and recorded in a dedicated form.

Group 3 (wearable device-assisted goal-directed quantitative activity management group): On the basis of the protocol in Group 2, patients in this group simultaneously wore a wearable activity tracker (Fitbit Charge 5). The device continuously monitored heart rate, respiratory rate, daily step count, sleep stages (deep sleep, light sleep, rapid eye movement), and blood oxygen saturation. The device was applied immediately upon the child's return to the surgical ward and was worn continuously except during charging (approximately 1 hour daily). A valid monitoring day was defined as ≥ 20 hours of wear time. Data points with heart rate < 30 bpm or > 250 bpm were considered artifacts and excluded from analysis. Wear-time adherence was recorded by the cloud platform and used as a quality control metric. In Group 3, the

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mean daily wear time was 22.1 ± 1.5 hours, indicating high adherence among pediatric participants. In addition to the standardized caregiver education provided to both intervention groups, caregivers in Group 3 received supplementary training on interpreting real-time data from the wearable device via a companion smartphone application. They were instructed on how to view daily step counts, sleep summaries, and goal achievement progress. Caregivers were specifically guided to use this objective feedback to provide positive reinforcement - such as verbal praise, sticker rewards, or small privileges - when the child met or exceeded the daily activity target. This additional training component was designed to actively engage families as collaborators in the data-driven recovery process.

Real-time data processing and feedback mechanism: Data from the wearable device were transmitted via Bluetooth to a dedicated tablet at the bedside and synchronized to a hospital-approved cloud platform at 15-minute intervals. A centralized monitoring dashboard was deployed at the nursing station to display real-time trends in heart rate, oxygen saturation, and step accumulation. Age-specific safety thresholds were preconfigured (e.g., heart rate $> (220 - \text{age}) \times 0.85$ or $\text{SpO}_2 < 94\%$ sustained for 2 minutes) to trigger automated alerts on the responsible nurse's handheld device. Upon alerting, the nurse would assess the child's tolerance and adjust the activity goal accordingly. During daily ward rounds, the attending team reviewed the previous 24-hour activity and sleep reports together with the child and caregivers. Based on this objective feedback, the next day's step target was negotiated and set collaboratively, forming a closed-loop of real-time monitoring, feedback, and adaptive goal adjustment.

Extraction of outcome data

All outcome indicators were retrospectively extracted from medical records, nursing records, the wearable device database, and follow-up records.

Primary outcome measures: Daily walking distance during the first three postoperative days: Extracted from nursing records and the wearable device database. For Groups 1 and 2, daily walking distance was jointly recorded by the

primary nurse and caregiver on the nursing record sheet. For Group 3, step count, walking distance, and activity duration automatically recorded by the smart wristband were exported from the cloud platform. All distance data were expressed as mean \pm standard deviation to assess early ambulation.

Time to first ambulation: Extracted from nursing records. Defined as the time interval from the end of surgery to the first documented instance (with or without assistance) of the patient standing and walking, recorded to the nearest hour.

Gastrointestinal function recovery time: Included time to first flatus and time to first defecation, extracted from nursing records to the nearest hour.

Length of hospital stay: Extracted from the medical record system, calculated as the number of days from the date of surgery to the date of discharge. Discharge criteria included normal diet, absence of fever, independent ambulation, and a visual analog scale (VAS) pain score < 3 .

Given the retrospective design, no cross-validation of the two measurement modalities (manual recording vs. automated step-based estimation) was performed, and this methodological discrepancy constitutes a limitation. Absolute walking distance values in Groups 1 and 2 should therefore be interpreted as approximations and compared with caution against those from Group 3.

Secondary outcome measures: Incidence of adverse events: Postoperative adverse events extracted from medical records included intestinal obstruction, abdominal distension, vomiting, wound infection, and fever. Incidence of adverse events = (number of patients experiencing adverse events/total number of enrolled patients) $\times 100\%$. Complication severity was graded according to the Clavien-Dindo classification system.

Patient and caregiver satisfaction: Satisfaction questionnaire scores were extracted from discharge follow-up records. The questionnaire contained 10 items (perceived nursing quality, clarity of postoperative instructions, overall satisfaction), scored from 0 to 10 for each item,

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with a total score ranging from 0 to 100. The questionnaire was pilot-tested in 10 families prior to study initiation, yielding a Cronbach's α of 0.86. Subsequent calculation using the full study sample (N = 150) confirmed good internal consistency (Cronbach's α = 0.84). While the instrument has not been formally validated against a gold-standard satisfaction scale, it was designed to capture key domains of patient and caregiver experience and was administered consistently across all three groups.

Exploratory measures (Group 3 only): The following parameters were extracted from the wearable device database: Sleep efficiency (total sleep time/time in bed \times 100%); Number of nocturnal awakenings; Heart rate variability (SDNN); Resting heart rate; Circadian rhythm amplitude (relative amplitude of the activity-rest rhythm calculated using the Lomb-Scargle periodogram method); Coefficient of variation of daytime activity; Additionally, pain scores (Visual Analog Scale) from postoperative days 1, 2, and 3 were extracted from pain assessment records to analyze the association between pain and sleep.

Statistical analysis

All statistical analyses were performed using SPSS 27.0 (IBM Corp., Armonk, NY, USA) and R software 4.2.1. Continuous variables are presented as mean \pm standard deviation ($\bar{x} \pm s$). Normality was assessed using the Shapiro-Wilk test. Inter-group comparisons were conducted using one-way analysis of variance (ANOVA), with post hoc pairwise comparisons performed using the Bonferroni method. For repeated measures data (e.g., daily walking distance during the first three postoperative days), repeated measures ANOVA was used to evaluate the effects of time, group, and their interaction. Categorical variables are expressed as frequency (percentage), and inter-group comparisons were performed using the chi-square test or Fisher's exact test (when expected frequencies were < 5).

To adjust for potential confounding factors, multivariate linear regression analysis was used to identify independent predictors of length of hospital stay. Variables included in the model were group, age, sex, appendicitis type, and BMI. Pearson correlation analysis was used to assess the relationship between

wearable-derived indicators and length of hospital stay. Based on data from Group 3, a logistic regression model (regularization parameter $C = 0.1$) was developed to predict postoperative complications (any Clavien-Dindo grade \geq II). Model performance was evaluated using leave-one-out cross-validation, and a receiver operating characteristic (ROC) curve was plotted to calculate the area under the curve (AUC). Feature importance was ranked by the absolute value of the regression coefficients.

Statistical significance was set at a two-sided $P < 0.05$. All missing data were handled using multiple imputation (5 imputations). To address the baseline imbalance in age among the three groups, a sensitivity analysis using propensity score matching (1:1:1 nearest-neighbor matching without replacement, caliper = 0.2) was performed. After matching, all baseline covariates were well balanced (standardized mean differences < 0.1), and the between-group differences in time to first flatus and length of hospital stay remained statistically significant ($P < 0.001$), confirming the robustness of the primary findings.

Results

Baseline characteristics

A total of 150 children were enrolled, with 50 cases in each group. Among the three groups, a statistically significant difference was observed in age ($F = 4.000$, $P = 0.020$), with Group 1 being younger (7.60 ± 2.10 years) than Group 2 (8.90 ± 2.91 years) and Group 3 (8.76 ± 2.50 years). The remaining baseline characteristics - including BMI, sex, guardian type, time from symptom onset, appendicitis type, and weight status - did not differ significantly (all $P > 0.05$). Given this age imbalance, age was included as a covariate in all multivariable models, and a propensity score-based sensitivity analysis was subsequently performed to verify the robustness of the findings (**Table 1**).

Comparison of postoperative activity levels

The daily walking distance of children in the three groups increased day by day on postoperative days 1, 2, and 3, with significant inter-group differences at each time point ($P < 0.001$). **Figure 2A** presents bar charts of daily walking distance in the three groups: Group 1

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Table 1. Baseline characteristics

Variable	Group 1 (n = 50)	Group 2 (n = 50)	Group 3 (n = 50)	F/ χ^2	P-value
Age (years)	7.60 ± 2.10	8.90 ± 2.91	8.76 ± 2.50	4.000	0.020
BMI	19.33 ± 2.80	20.04 ± 3.54	19.34 ± 2.76	0.891	0.412
Gender (Male)	32 (64.0%)	38 (76.0%)	31 (62.0%)	2.607	0.272
Guardian (Parents)	33 (66.0%)	30 (60.0%)	29 (58.0%)	0.731	0.694
Onset time (< 24 h)	24 (48.0%)	27 (54.0%)	34 (68.0%)	4.290	0.117
Appendicitis (Suppurative)	25 (50.0%)	23 (46.0%)	25 (50.0%)	0.213	0.899
Weight status (Normal)	38 (76.0%)	35 (70.0%)	35 (70.0%)	0.595	0.743
Overweight	7 (14.0%)	6 (12.0%)	11 (22.0%)	2.083	0.353
Obese	5 (10.0%)	9 (18.0%)	4 (8.0%)	2.652	0.266

Abbreviation: BMI, body mass index.

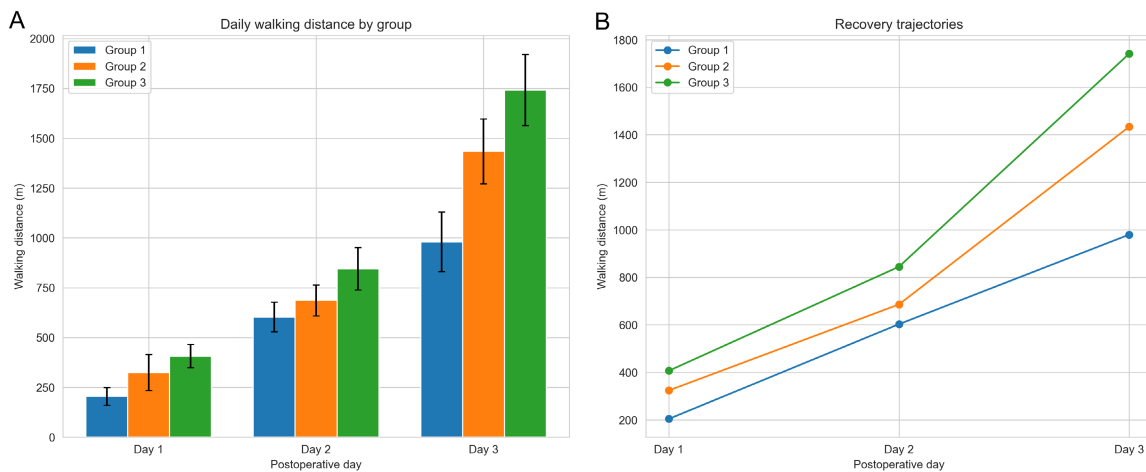


Figure 2. Comparison of daily activity within the first three postoperative days among the three groups. A. Bar chart of daily walking distance (mean ± SD). Group 3 > Group 2 > Group 1 on all days ($P < 0.001$); B. Line chart of recovery trajectories. Repeated measures ANOVA showed significant time × group interaction ($P < 0.001$). Abbreviations: SD, standard deviation; ANOVA, analysis of variance.

was 204.08 ± 44.30 m, 602.94 ± 74.20 m, and 979.75 ± 149.42 m, respectively; Group 2 was 323.95 ± 90.15 m, 686.10 ± 77.56 m, and 1433.84 ± 162.63 m, respectively; Group 3 was 406.74 ± 58.20 m, 844.70 ± 106.85 m, and 1741.21 ± 178.30 m, respectively. One-way ANOVA showed statistically significant intergroup differences on day 1 ($F = 115.556$, $P < 0.001$), day 2 ($F = 98.655$, $P < 0.001$), and day 3 ($F = 273.215$, $P < 0.001$) (**Table 2**). Pairwise comparisons revealed that the daily walking distance in Group 3 was significantly higher than that in Group 2 and Group 1, and Group 2 was also significantly higher than Group 1 (all $P < 0.001$). **Figure 2B** shows line charts of postoperative recovery trajectories in the three groups. Repeated-measures ANOVA demonstrated significant main effects of time, group, and time × group interaction (interaction

$F = 28.601$, $P < 0.001$), indicating the fastest recovery rate in Group 3.

Comparison of postoperative recovery indicators

There were significant differences in time to first ambulation, time to first flatus, time to first defecation, and length of hospital stay among the three groups ($P < 0.001$), as detailed in **Table 3**. Time to first ambulation (**Figure 3A**): Group 1 was 18.09 ± 5.02 h, Group 2 was 15.13 ± 2.60 h, and Group 3 was 9.52 ± 2.39 h ($F = 75.256$, $P < 0.001$). Time to first flatus (**Figure 3B**): Group 1 was 23.28 ± 5.45 h, Group 2 was 17.65 ± 3.71 h, and Group 3 was 13.17 ± 4.28 h ($F = 62.255$, $P < 0.001$). Time to first defecation (**Figure 3C**): Group 1 was 38.51 ± 4.62 h, Group 2 was 33.91 ± 4.18 h, and Group

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Table 2. Walking distance in first three days

Day	Group 1 (n = 50)	Group 2 (n = 50)	Group 3 (n = 50)	F	P-value
Day 1	204.08 ± 44.30	323.95 ± 90.15	406.74 ± 58.20	115.556	< 0.001
Day 2	602.94 ± 74.20	686.10 ± 77.56	844.70 ± 106.85	98.655	< 0.001
Day 3	979.75 ± 149.42	1433.84 ± 162.63	1741.21 ± 178.30	273.215	< 0.001
Repeated measures ANOVA (time × group)				28.601	< 0.001

Abbreviation: ANOVA, analysis of variance.

Table 3. Postoperative recovery indicators

Indicator	Group 1 (n = 50)	Group 2 (n = 50)	Group 3 (n = 50)	F	P-value
First ambulation (h)	18.09 ± 5.02	15.13 ± 2.60	9.52 ± 2.39	75.256	< 0.001
First flatus (h)	23.28 ± 5.45	17.65 ± 3.71	13.17 ± 4.28	62.255	< 0.001
First defecation (h)	38.51 ± 4.62	33.91 ± 4.18	27.77 ± 3.46	85.710	< 0.001
Hospital stay (d)	8.29 ± 1.54	5.60 ± 0.98	4.28 ± 0.58	170.548	< 0.001

3 was 27.77 ± 3.46 h (F = 85.710, P < 0.001). Length of hospital stay (**Figure 4**): Group 1 was 8.29 ± 1.54 d, Group 2 was 5.60 ± 0.98 d, and Group 3 was 4.28 ± 0.58 d (F = 170.548, P < 0.001). Compared with Group 1, Group 3 showed a reduction of 8.57 h in time to first ambulation, 10.11 h in time to first flatus, 10.74 h in time to first defecation, and 4.01 d in length of hospital stay.

Multivariate linear regression analysis showed that group remained an independent predictor of length of hospital stay after adjusting for age, sex, type of appendicitis, and BMI. Compared with Group 1, length of hospital stay was significantly shorter in Group 2 ($\beta = -2.625$, 95% CI: -3.076 to -2.173, P < 0.001) and Group 3 ($\beta = -3.977$, 95% CI: -4.422 to -3.532, P < 0.001) (**Table 4**). Age, sex, type of appendicitis, and BMI showed no significant association with length of hospital stay.

Comparison of adverse events and satisfaction

The incidence of postoperative adverse events differed significantly among the three groups ($\chi^2 = 9.750$, P = 0.008). **Figure 5A** presents a stacked bar chart of adverse event types: 15 adverse events occurred in Group 1 (30.0%), including abdominal distension in 7 cases, vomiting in 6 cases, wound infection in 1 case, and fever in 1 case; 12 adverse events occurred in Group 2 (24.0%), including intestinal obstruction in 6 cases, abdominal distension in 2 cases, vomiting in 3 cases, and wound infection in 1 case; 3 adverse events occurred in Group 3 (6.0%), including intestinal obstruction

in 1 case, vomiting in 1 case, and wound infection in 1 case. Pairwise comparisons showed that the incidence of adverse events in Group 3 was significantly lower than that in Group 1 and Group 2 (P < 0.05), whereas no significant difference was observed between Group 1 and Group 2 (**Table 5**).

Patient satisfaction scores differed significantly among the three groups (P < 0.001). **Figure 5B** shows box plots of satisfaction scores: Group 1 was 91.59 ± 3.34, Group 2 was 95.26 ± 1.30, and Group 3 was 98.32 ± 1.28 (F = 117.602, P < 0.001). Pairwise comparisons revealed that satisfaction in Group 3 was significantly higher than that in Group 2 and Group 1, and Group 2 was also significantly higher than Group 1 (**Table 5**).

Analysis of wearable-derived indicators (Group 3)

Physiological indicators monitored by wearable devices in Group 3 showed the following trends: sleep efficiency (**Figure 6A**) was 75.91% ± 4.53% on the first postoperative night, increased to 84.77% ± 5.87% on the second night, and reached 92.58% ± 5.83% on the third night, showing a night-by-night improvement. Heart rate variability (HRV) recovery trajectory (**Figure 6B**): HRV (SDNN) remained persistently low within 3 days postoperatively in children with complications (32.70 ± 5.25 ms on day 1, 31.45 ± 5.44 ms on day 2, 32.42 ± 5.93 ms on day 3), whereas it remained at a high level in children without complications (42.00 ± 10.53 ms on day 1, 41.75 ± 9.42 ms

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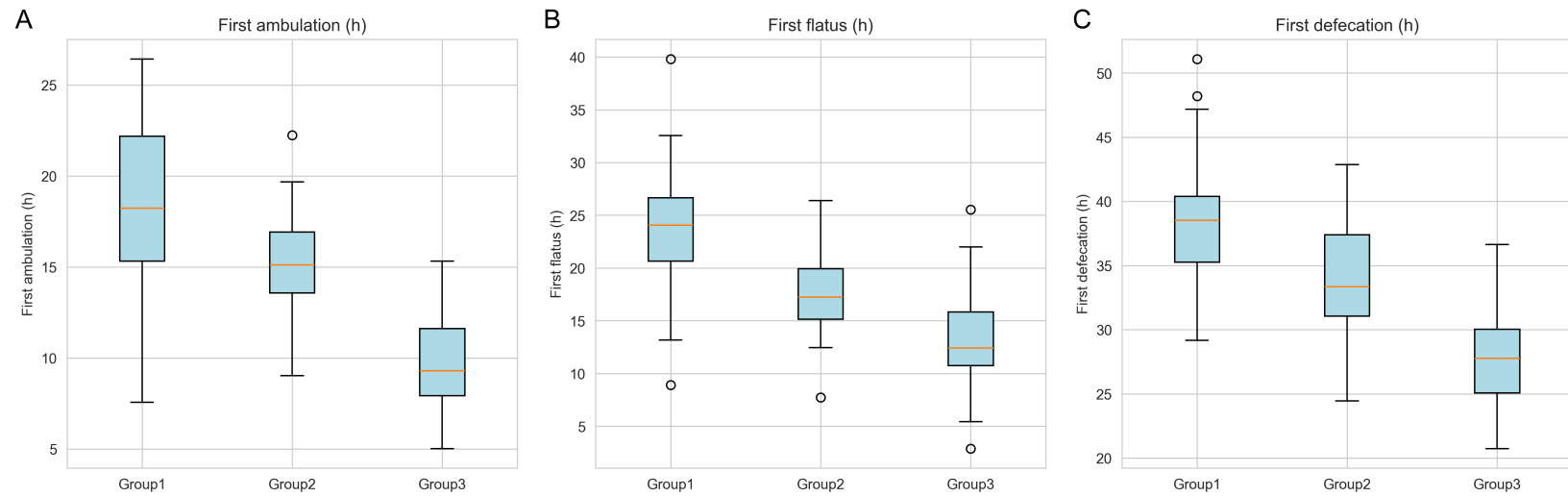


Figure 3. Comparison of postoperative recovery times among the three groups. A. First ambulation; B. First flatus; C. First defecation; Group 3 had the shortest times, followed by Group 2 and Group 1 (all $P < 0.001$).

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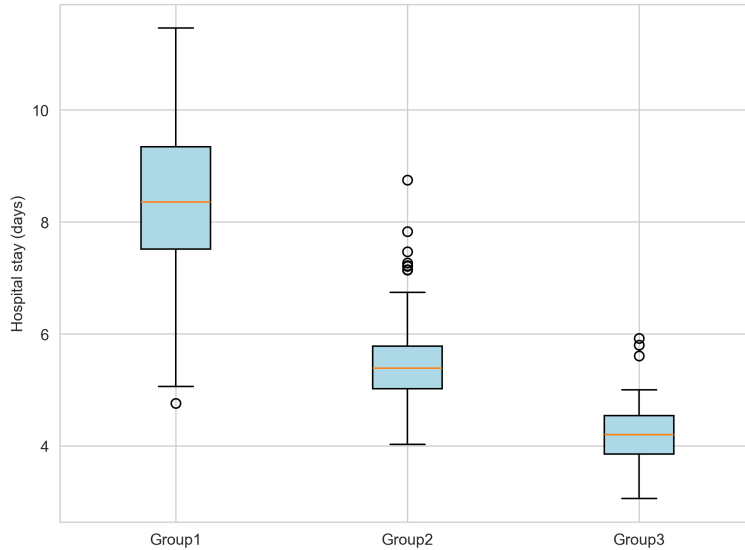


Figure 4. Comparison of hospital stay among the three groups.

Table 4. Multivariable linear regression of hospital stay

Variable	β	Lower 95% CI	Upper 95% CI	P-value
Intercept	9.476	8.185	10.768	< 0.001
Group 2 vs 1	-2.625	-3.076	-2.173	< 0.001
Group 3 vs 1	-3.977	-4.422	-3.532	< 0.001
Age	-0.026	-0.098	0.046	0.472
Gender (Female)	-0.057	-0.442	0.329	0.772
Suppurative appendicitis	0.069	-0.29	0.428	0.704
BMI	-0.052	-0.111	0.007	0.085

Abbreviations: CI, confidence interval; BMI, body mass index.

on day 2, 41.25 ± 8.70 ms on day 3). Relationship between circadian rhythm amplitude and length of hospital stay (**Figure 6C**): circadian rhythm amplitude was 0.46 ± 0.13 in children with a hospital stay ≤ 4 days, higher than 0.42 ± 0.11 in those with a hospital stay > 4 days, but the difference was not statistically significant ($t = 0.880$, $P = 0.386$).

Pain score analysis (**Figure 7A**) showed a gradual downward trend from postoperative day 1 to day 3: 4.34 ± 2.19 on day 1, 4.29 ± 2.19 on day 2, and 4.19 ± 1.84 on day 3. Correlation analysis (**Figure 7B**) demonstrated a significant negative correlation between pain score on day 1 and sleep efficiency on the same day ($r = -0.631$, $P < 0.001$), indicating that higher pain was associated with lower sleep efficiency.

In addition, correlation analysis between pain scores and length of hospital stay (**Table 6**) showed significant positive correlations for pain scores on day 1 ($r = 0.330$, $P = 0.019$) and day 2 ($r = 0.387$, $P = 0.006$), whereas no significant correlation was found for pain scores on day 3 ($r = 0.128$, $P = 0.377$). This suggests that early postoperative pain severity significantly affects length of hospital stay.

Other wearable indicators, including resting heart rate ($r = 0.063$, $P = 0.666$) and coefficient of variation of daytime activity ($r = -0.172$, $P = 0.232$), showed no statistically significant correlations with length of hospital stay (**Table 6**).

Exploratory analysis of wearable-derived features and complication risk

As an exploratory analysis, a logistic regression model was fitted using wearable data from Group 3 to identify potential early markers of postoperative complications. Given the limited number of adverse events ($n = 3$), this analysis is considered hypothesis-generating rather than clinically applicable. The ROC curve (**Figure 8A**) showed an area under the curve of 0.603 for predicting postoperative complications. Feature importance (**Figure 8B**) ranked the contribution of each feature (absolute coefficient value) as follows: sleep efficiency on day 1 (0.280), HRV on day 2 (0.155), number of nighttime awakenings (0.148), HRV on day 1 (0.055), resting heart rate (0.027), sleep efficiency on day 2 (0.024), circadian rhythm amplitude (0.004), and coefficient of variation of daytime activity (0.003). Risk trajectories of children with complications (**Figure 8C**) showed a downward trend in predicted risk from postoperative day 1 to day 2 in the three complicated cases: Patient 1 decreased from 0.357 to 0.038, Patient 2 from 0.054 to 0.002, and

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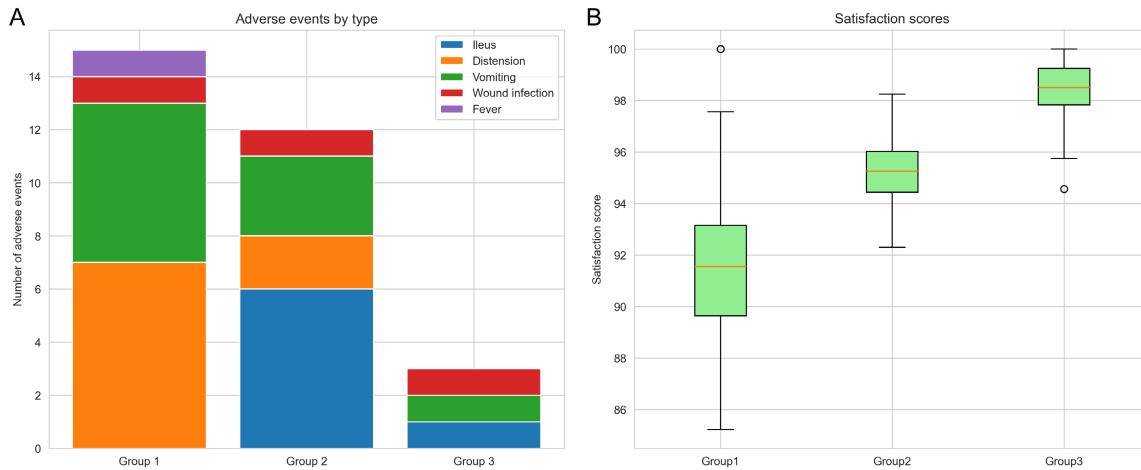


Figure 5. Adverse events and satisfaction. A. Stacked bar chart of adverse event types. Group 3 had the lowest incidence (6%, $P = 0.008$); B. Satisfaction scores (boxplot). Group 3 > Group 2 > Group 1 ($P < 0.001$).

Table 5. Adverse events and satisfaction

Group	Adverse events n (%)	Satisfaction score	Intestinal obstruction	Abdominal distension	Vomiting	Wound infection	Fever
Group 1	15 (30.0%)	91.59 ± 3.34	0 (0.0%)	7 (14.0%)	6 (12.0%)	1 (2.0%)	1 (2.0%)
Group 2	12 (24.0%)	95.26 ± 1.30	6 (12.0%)	2 (4.0%)	3 (6.0%)	1 (2.0%)	0 (0.0%)
Group 3	3 (6.0%)	98.32 ± 1.28	1 (2.0%)	0 (0.0%)	1 (2.0%)	1 (2.0%)	0 (0.0%)
χ^2/F	9.750	117.602					
P -value	0.008	< 0.001					

Patient 3 from 0.424 to 0.036, suggesting the model has certain early warning potential.

Discussion

As a core component of Enhanced Recovery After Surgery (ERAS), early ambulation has been proven to effectively promote gastrointestinal function recovery, reduce complications, and shorten hospital stays in adult surgical practice [15, 16]. However, the implementation of this concept in pediatric patients faces numerous challenges. Physiological discomfort such as postoperative pain and fear in children, combined with caregivers' traditional belief that "rest is necessary after surgery", results in generally poor adherence of children to early mobilization [17, 18]. Meanwhile, the lack of standardized and quantified protocols for postoperative activity guidance in children limits the clinical application of ERAS principles in the pediatric field [19, 20]. Therefore, the development of a scientific and quantifiable postoperative activity strategy for children carries important clinical significance.

This retrospective study demonstrates that wearable device-assisted, goal-directed early ambulation significantly improves postoperative activity compliance in children. The wearable-assisted group achieved significantly longer walking distances in the first three postoperative days than the other two groups ($P < 0.001$), indicating that real-time feedback and structured goals effectively enhance participation. This is consistent with previous findings that technology-assisted activity management improves surgical rehabilitation outcomes [21-23]. The underlying mechanisms may include: first, behavioral motivational effects. Real-time visualized step counts and progress convert abstract goals into concrete achievements, aligning with Bandura's self-efficacy theory and stimulating children's achievement motivation through positive reinforcement [24]. Second, evidence-based intensity control. Continuous monitoring of heart rate and respiratory variability allows clinicians to dynamically adjust activity intensity according to safety thresholds, ensuring a safe and efficient rehabilitation process. Third, promotion of family engagement. A

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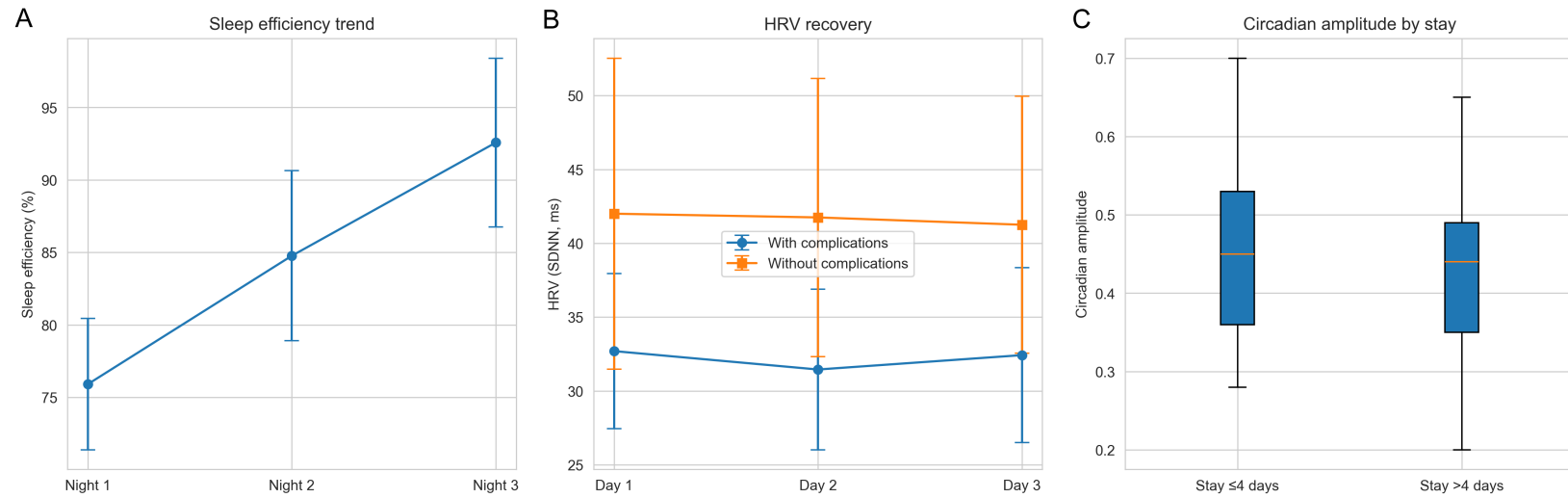


Figure 6. Wearable-derived metrics in Group 3. A. Sleep efficiency trend (mean \pm SD). Progressive improvement over three nights; B. HRV (SDNN) recovery trajectories. Children without complications had higher HRV; C. Circadian amplitude by hospital stay. No significant difference ($P = 0.386$). Abbreviations: SD, standard deviation; HRV, heart rate variability; SDNN, standard deviation of normal-to-normal intervals.

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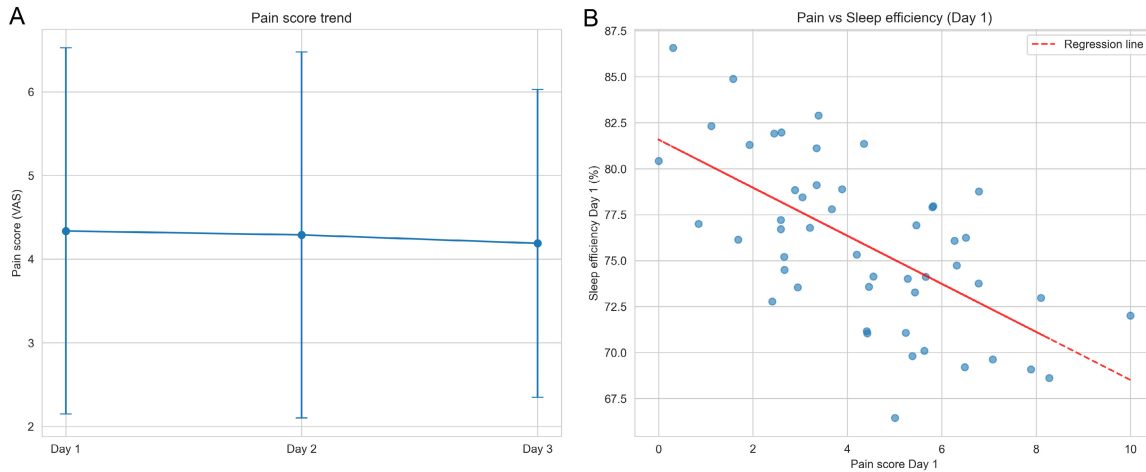


Figure 7. Pain score analysis in Group 3. A. Pain score trend; B. Scatter plot of pain score vs sleep efficiency (Day 1).

Table 6. Wearable metrics and correlation with hospital stay (Group 3)

Metric	Mean \pm SD	Correlation with stay	P-value
Sleep efficiency (%)	84.57 \pm 4.95	-0.441	0.001
Night awakenings	2.39 \pm 1.23	0.255	0.074
HRV (SDNN)	41.10 \pm 9.34	-0.283	0.046
Resting HR	83.67 \pm 6.13	0.063	0.666
Circadian amplitude	0.43 \pm 0.11	-0.357	0.011
Daytime activity CV	0.39 \pm 0.08	-0.172	0.232
Pain score Day 1	4.34 \pm 2.19	0.330	0.019
Pain score Day 2	4.29 \pm 2.19	0.387	0.006
Pain score Day 3	4.19 \pm 1.84	0.128	0.377

Abbreviations: HRV, heart rate variability; SDNN, standard deviation of normal-to-normal intervals; CV, coefficient of variation.

“clinician-child-parent” interactive network is formed via mobile applications, and mechanisms such as check-ins in WeChat groups strengthen compliance and social support [25, 26].

In addition to improving activity compliance, this study found that wearable device-assisted ambulation significantly accelerated gastrointestinal function recovery and shortened hospital stays. Children managed with wearable device assistance had significantly shorter times to first flatus, first defecation, and discharge than the other two groups ($P < 0.001$), with the lowest incidence of adverse events. Compared with the conventional care group, the wearable-assisted group showed a reduction of 8.57 hours in time to first ambulation,

10.11 hours in time to first flatus, and 4.01 days in hospital stay. The mechanisms by which early ambulation promotes gastrointestinal recovery involve mechanical stimulation of intestinal peristalsis and improved abdominal blood circulation via upright posture and walking; moderate activity also reduces stress hormone levels and alleviates systemic inflammatory responses [27, 28]. The results of this study are consistent with those reported by Xu et al. [29] and de Dorrell et al. [30], confirming that step count monitoring can serve as an objective measure of functional recovery, and integrating wearable devices into ERAS protocols significantly shortens hospital stays [31].

Another important finding of this study is that wearable device-assisted management significantly improved patient and family satisfaction. Digital feedback, goal-directed guidance, and collaborative communication encouraged family members to participate more actively in post-operative care and optimized the rehabilitation experience. Previous studies have confirmed that digital health interventions incorporating real-time monitoring and interactive feedback significantly enhance parents’ understanding, engagement, and satisfaction with the rehabilitation process [32], reduce uncertainty and anxiety [33], and increase motivation and adherence to healthy behaviors among children and caregivers [34]. When combined with structured communication, wearable technologies serve as an important bridge between

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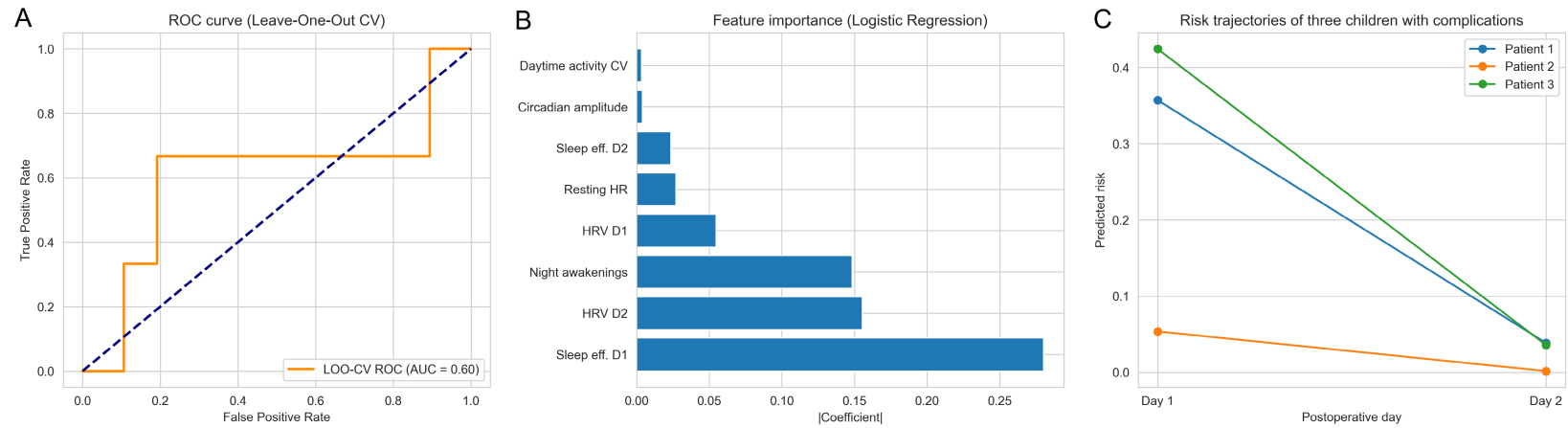


Figure 8. Exploratory analysis of wearable-derived features and postoperative complication risk in Group 3. A. ROC curve (LOO-CV). AUC = 0.603; B. Feature importance (absolute coefficients). Top predictors: sleep efficiency day1, HRV day2, night awakenings; C. Risk trajectories for three complication cases. Risk decreased from day1 to day2 in all cases. Abbreviations: ROC, receiver operating characteristic; LOO-CV, leave-one-out cross-validation; AUC, area under the curve; HRV, heart rate variability.

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clinical management and family participation, transforming family members from passive observers into active contributors and improving overall care quality.

Valuable exploratory findings were obtained from the analysis of wearable-derived indicators. Sleep efficiency showed a night-by-night improvement over the three postoperative nights and was significantly negatively correlated with hospital stay ($r = -0.441$, $P = 0.001$), suggesting that sleep quality is an important factor affecting rehabilitation speed. As an indicator of autonomic nervous function, heart rate variability (HRV) remained at a high level in children without complications but persistently low in those with complications postoperatively, consistent with previous reports linking reduced HRV to adverse outcomes. Pain score analysis revealed significant positive correlations between pain scores on postoperative days 1 and 2 and hospital stay ($r = 0.330$, $P = 0.019$; $r = 0.387$, $P = 0.006$), as well as a significant negative correlation between day 1 pain score and sleep efficiency on the same day ($r = -0.631$, $P < 0.001$). This indicates that early postoperative pain control not only directly affects children's comfort but may also indirectly influence the recovery process by disrupting sleep. These findings suggest that when implementing early ambulation protocols, equal attention should be paid to pain management and sleep preservation to establish a multi-dimensional rehabilitation support system. It must be emphasized that the logistic regression model presented herein is strictly exploratory. The small number of complication events ($n = 3$) precludes reliable estimation of predictive performance ($AUC = 0.603$), and the identified features (sleep efficiency, HRV) should be viewed as candidate markers for future prospective validation rather than as a clinically deployable prediction tool.

This study has several limitations. First, the retrospective design may introduce selection bias and information bias; although multiple imputation and multivariate regression adjustment were applied, the influence of unmeasured confounding factors cannot be completely eliminated. Specifically, the three groups were not fully balanced at baseline, with a statistically significant difference in age ($P = 0.020$). Although multivariate regression and propensity score-based sensitivity analyses confirmed the

independence of the intervention effect, age-related factors such as intrinsic mobility and pain perception may still exert residual confounding. It should be noted, however, that the intervention protocol incorporated age-stratified activity goals, which inherently accounted for developmental differences in physical capacity and may have partially mitigated this imbalance. Second, the sample was limited to pediatric patients with appendicitis from a single center, excluding cases of perforated appendicitis and those converted to open surgery, resulting in limited generalizability of the results. Third, psychological outcomes such as anxiety and fear were not systematically evaluated, yet these factors may mediate the intervention effect. Fourth, wrist-worn devices have limitations in terms of comfort and wearing adherence, and pediatric-specific sensors need to be developed. Fifth, follow-up only focused on short-term in-hospital outcomes and did not assess long-term rehabilitation effects. Finally, the retrospective design precludes the establishment of causal relationships, and the conclusions require validation by prospective randomized controlled trials. Furthermore, walking distance in Groups 1 and 2 was manually recorded by nursing staff and caregivers using corridor markers, whereas Group 3 utilized automated step-based distance estimation from the wearable device. This methodological discrepancy may introduce measurement bias and limit the absolute comparability of daily activity values. Nevertheless, the consistent and substantial between-group differences in recovery trajectories, corroborated by objectively timed outcomes (e.g., time to first flatus, length of stay), support the clinical validity of the observed trend.

Future research should be extended to various pediatric surgical procedures and conduct multicenter prospective randomized controlled trials to verify generalizability. Multidimensional physiological and psychological indicators should be integrated to further explore the mechanisms by which wearable devices regulate inflammation, pain, and emotional states. Developing integrated multimodal sensor devices more suitable for children and exploring the application of artificial intelligence in personalized rehabilitation protocol formulation and complication early warning will be important directions. Ultimately, the deep integration of

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wearable data into ERAS pathways is expected to achieve truly individualized and precise rehabilitation management in pediatric surgery.

From a nursing perspective, this study highlights the critical role of nurses in technology integration. Nurses are central to patient education, monitoring, and communication, and wearable devices provide real-time data to support individualized care decisions. Incorporating theories of self-efficacy and family-centered care into interventions can further enhance rehabilitation motivation and adherence. Establishing standardized technology-assisted ambulation protocols embedded within the ERAS framework will promote the transition of pediatric perioperative care from experience-driven to data-driven practice. In conclusion, wearable device-assisted goal-directed ambulation can facilitate faster and safer recovery, improve care quality and family satisfaction, and provide a promising approach for pediatric surgical nursing.

Conclusion

This retrospective cohort study evaluated the efficacy of wearable technology-based goal-directed quantitative activity management in postoperative rehabilitation among children undergoing appendectomy. The results demonstrated that this management model significantly improved children's adherence to early postoperative mobilization and markedly increased walking distance within the first three days after surgery. Meanwhile, it effectively shortened the time to first ambulation, time to first flatus, and length of hospital stay, thereby promoting early recovery of gastrointestinal function. Furthermore, children managed with wearable device assistance exhibited the lowest incidence of postoperative adverse events and the highest satisfaction scores among patients and caregivers.

From the perspective of retrospective data analysis, this study provides real-world clinical evidence supporting enhanced recovery after surgery in pediatric surgery. The integration of wearable monitoring technology with staged, quantitative activity protocols-via real-time feedback and goal-oriented motivation-effectively addresses the clinical challenge of poor adherence to early mobilization in children after surgery, while also facilitating family engagement and physician-patient collaboration.

Despite limitations including a single-center retrospective design, the findings of this study indicate that wearable technology-based goal-directed quantitative activity management serves as an effective strategy for optimizing postoperative care in children with appendicitis. It can accelerate recovery, reduce complication risks, and improve care quality and patient satisfaction, offering valuable evidence for the clinical practice of enhanced recovery after surgery in pediatric surgery.

Disclosure of conflict of interest

None.

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