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Remimazolam versus propofol for general anaesthesia in children undergoing laparoscopic inguinal hernia repair: a propensity score- matched retrospective cohort study

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Remimazolam versus propofol for general anaesthesia in children undergoing laparoscopic inguinal hernia repair: a propensity score-matched retrospective cohort study

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Abstract

Background: Remimazolam is an ultra-short-acting benzodiazepine with a favourable safety profile, but comparative evidence against propofol in paediatric surgery remains limited. We compared remimazolam-based and propofol-based general anaesthesia in children undergoing laparoscopic inguinal hernia repair.

Methods: In this single-centre retrospective cohort study, children aged 3–12 years with American Society of Anesthesiologists physical status I–II who underwent elective laparoscopic inguinal hernia repair between April 2024 and May 2025 were identified from routinely collected clinical records. Children receiving remimazolam or propofol were matched 1:1 by nearest-neighbour propensity score matching with a 0.05 caliper. Emergence time was the primary outcome; secondary outcomes included airway-device removal time, intraoperative haemodynamic instability, adverse events within 24 h, postoperative recovery, length of stay and Pediatric Quality of Life Inventory 4.0 scores. Continuous and categorical variables were compared using

appropriate parametric or non-parametric tests, chi-square or Fisher's exact tests, and mixed-effects analysis for repeated quality-of-life measurements.

Results: After matching, 120 children were analysed in each group. Remimazolam was associated with shorter emergence time (median 11.5 vs 18.2 min) and airway-device removal time (13.2 vs 20.4 min; both $P < 0.001$), less intraoperative haemodynamic instability (15.0% vs 25.8%; $P = 0.034$), and fewer adverse events within 24 h (8.3% vs 35.8%; $P < 0.001$). Emergence agitation occurred in 3.3% versus 26.7%, and nausea or vomiting in 4.2% versus 18.3%. Oral intake, ambulation and hospital discharge occurred earlier in the remimazolam group. PedsQL scores were higher at 1 week and 1 month after surgery, with between-group differences exceeding the reported minimal clinically important difference.

Conclusions: In this propensity score-matched retrospective cohort of children undergoing laparoscopic inguinal hernia repair, remimazolam use was associated with shorter emergence and airway-device removal times and a lower observed incidence of selected postoperative adverse events than propofol. Higher postoperative PedsQL scores were also observed in the remimazolam group at follow-up. These findings should be interpreted cautiously because of the retrospective, single-centre design, the possibility of residual confounding, and limitations in the assessment of patient-reported outcomes. Prospective studies are needed to confirm these associations and evaluate their clinical significance.

Keywords: Remimazolam; Propofol; Paediatric anaesthesia; Emergence agitation; Health-related quality of life

1 Background

Children's cardiovascular, respiratory, and metabolic systems are physiologically immature, resulting in tolerance to anaesthetic agents that differs substantially from that of adults. This

physiological immaturity is particularly pronounced among children aged 3–6 years, who have limited cardiovascular regulatory capacity, reduced respiratory reserve, and heightened sensitivity to central nervous system depressants, placing them at greater risk of anaesthesia-related adverse events. Postoperative emergence agitation not only increases the physical risk of wound dehiscence and falls from bed, but may also provoke fear of medical procedures, prolong hospital stay, and adversely affect long-term behavioural development and return to school [1].

Inguinal hernia is one of the most common surgical conditions of childhood. Epidemiological studies report a global incidence of approximately 1%–4%, with a higher proportion among male children and a markedly elevated incidence among preterm infants [2,3]. According to the Global Burden of Disease study, more than 32.5 million prevalent cases of hernia were recorded worldwide as of 2019 [4]. In low- and middle-income countries, paediatric inguinal hernia accounted for 58.4% of global cases in 2023 but contributed 83.8% of deaths and 74.0% of the associated disease burden, with infants under one year of age accounting for more than 85% of deaths [4]. Millions of children undergo inguinal hernia surgery each year, and although surgical techniques continue to advance—including the adoption of laparoscopic and robot-assisted approaches [2]—the quality of perioperative anaesthetic management continues to directly shape health outcomes and healthcare system efficiency at a population level. Within the framework of United Nations Sustainable Development Goal 3 (SDG 3)—"ensure healthy lives and promote well-being for all at all ages"—optimizing paediatric perioperative care, reducing preventable postoperative complications, and promoting early recovery represent key pathways toward this global health agenda.

Postoperative chronic pain is likewise a long-term concern that should not be overlooked. Widder et al. [5] reported a 3.4% incidence of chronic pain at 3 months after paediatric inguinal hernia

repair, with higher risk among girls, older children, and those with a prior history of chronic pain, further underscoring the importance of perioperative pain management for long-term paediatric health outcomes. Propofol remains one of the most commonly used intravenous agents in paediatric general anaesthesia, but its dose-dependent respiratory depression, haemodynamic fluctuation, and association with postoperative agitation remain core safety concerns in clinical practice. A meta-analysis by Xiao et al. [6] showed that prophylactic propofol administered on a sevoflurane background reduced the incidence of emergence agitation (RR = 0.51, 95% CI 0.39–0.67), although propofol itself is still associated with injection pain and hypotension [7]. In non-intubated general anaesthesia, the incidence of severe respiratory depression in the propofol group has been reported as high as 44.2% [8].

With the global adoption of Enhanced Recovery After Surgery (ERAS) principles in paediatric surgery [9,10], the goals of anaesthetic management have shifted from simply "maintaining intraoperative stability" toward "promoting early postoperative recovery, improving long-term quality of life, and enhancing healthcare resource efficiency." Laparoscopic and minimally invasive techniques have already demonstrated benefits in reducing postoperative pain and accelerating recovery [2], and the choice of anaesthetic agent is an equally important component of this shift. Remimazolam is a novel ultra-short-acting benzodiazepine that produces sedation and anaesthesia through selective binding to central benzodiazepine receptors [11]. Its distinctive pharmacological profile—rapid metabolism by plasma esterases independent of hepatic or renal function, a short elimination half-life (approximately 45–70 minutes), absence of active metabolite accumulation, mild cardiorespiratory effects, and rapid reversal with flumazenil [12,13]—makes it theoretically well suited to children whose physiological systems are still maturing. A meta-analysis by Peng et al. [14] found that, compared with propofol, remimazolam significantly

reduced heart rate fluctuation (MD = −4.99) and mean arterial pressure fluctuation (MD = −5.91) during induction of general anaesthesia, with a lower overall incidence of adverse events (OR = 0.40, 95% CI 0.28–0.58). In children undergoing adenotonsillectomy, Wu et al. [15] reported a significantly lower incidence of emergence agitation in the remimazolam group (12%) than in the propofol group (30%).

Although a body of evidence for remimazolam has accumulated in adult anaesthesia, evidence in paediatric populations remains limited in three respects. First, most existing studies focus on immediate anaesthetic efficacy and short-term safety, with little comprehensive assessment of postoperative recovery trajectories, healthcare resource utilisation, or long-term quality of life—outcomes of core public health relevance. Second, systematic data on dose-response and tolerability across different paediatric age groups are lacking, and evidence is particularly sparse for children aged 3–6 years. Third, existing studies have not evaluated anaesthetic strategies through the lens of "reducing age-related health inequities," nor have they adequately addressed long-term outcomes such as postoperative chronic pain [5]. A review by Kuklin and Hansen [16] noted that only two randomised controlled trials and a small number of prospective cohort studies have examined remimazolam use in children, together comprising fewer than 700 patients, with most other evidence limited to case reports. A scoping review by Pieri et al. [17] likewise emphasised that, although preliminary evidence suggests remimazolam is safe and effective for paediatric anaesthesia and sedation, further research is needed to determine optimal dosing and establish standardised protocols. Ramamurthi and Hammer [18] concluded that remimazolam may offer several advantages over propofol, but that safety and efficacy data in infants and children remain insufficient. Because younger children are the most physiologically vulnerable, the most sensitive to anaesthetic stress, and the most susceptible to lasting postoperative psychological

effects, there is an urgent need for comparative effectiveness research conducted in real-world clinical settings to systematically evaluate the value of remimazolam-based regimens for postoperative recovery, healthcare resource utilisation, and quality of life, thereby providing evidence to inform paediatric perioperative care policy.

This retrospective cohort study used hospital electronic medical record, anaesthesia information system, and postoperative follow-up database data to identify children aged 3–12 years who underwent elective laparoscopic inguinal hernia repair at the First Affiliated Hospital of Henan Medical University between April 2024 and May 2025, comparing remimazolam and propofol anaesthesia with respect to postoperative recovery, healthcare resource utilisation, and health-related quality of life. Because the choice of anaesthetic agent was made independently by the treating clinician based on the child's clinical circumstances, propensity score matching was used to control for potential confounding, and analyses were stratified by age (3–6 years vs. 7–12 years) to evaluate differential benefit across age groups. The findings are intended to provide real-world evidence to optimize paediatric perioperative care pathways, advance the implementation of ERAS in paediatric surgery, and help reduce age-related inequities in child health.

2 Methods

2.1 Study Design

This was a single-centre retrospective cohort study. Data were retrospectively extracted from the hospital electronic medical record system (HIS), the anaesthesia information system, and the postoperative follow-up database for children who underwent elective laparoscopic inguinal hernia repair at the First Affiliated Hospital of Henan Medical University between April 2024 and May 2025. This study was approved by the Ethics Committee of the First Affiliated Hospital of Henan Medical University (approval number: EC-024-486). All procedures were performed in

accordance with the principles of the Declaration of Helsinki. Given that this study performed secondary analysis of de-identified routine clinical records, did not interfere with clinical management, and collected no additional biological specimens, the Ethics Committee granted a waiver of written informed consent.

2.2 Study Population and Eligibility Criteria

Inclusion criteria: (1) diagnosis of indirect or direct inguinal hernia based on clinical examination and ultrasonography; (2) scheduled for elective laparoscopic hernia repair (transumbilical single-port high ligation of the hernia sac or multi-port laparoscopic repair); (3) age 3–12 years, either sex; (4) American Society of Anesthesiologists (ASA) physical status class I–II; (5) expected operative duration ≤60 minutes, with no intraoperative blood transfusion anticipated; operative duration was defined as the interval from skin incision to skin closure as recorded in the anaesthesia information system.

Exclusion criteria: (1) known allergy to remimazolam, propofol, fentanyl, or other anaesthetic agents; (2) severe hepatic or renal insufficiency (Child–Pugh class ≥B, or estimated glomerular filtration rate <60 $mL \cdot min^{-1} \cdot 1.73\ m^{-2}$); (3) congenital cardiovascular disease, coagulation disorders, or neurological disease (e.g., epilepsy, cerebral palsy); (4) preoperative respiratory tract infection, dyspnoea, or obstructive sleep apnoea; respiratory infection, diarrhoea, or other illness within the preceding week; or preoperative use of analgesic or sedative medication; (5) use of benzodiazepines or agents affecting drug metabolism within the preceding month; (6) missing data for key variables exceeding 20% (the threshold was applied to each prespecified key variable within an individual record); (7) intraoperative change of anaesthetic regimen; (8) concurrent additional surgical procedures.

2.3 Grouping and Confounder Control

Children were assigned to a remimazolam group (primary intraoperative sedative agent: remimazolam) or a propofol group (primary intraoperative sedative agent: propofol) based on the anaesthesia record and medication orders documenting actual intraoperative drug administration. Fentanyl and vecuronium were used concomitantly with the primary sedative in both groups.

Because the anaesthetic regimen was determined by the anaesthesiologist based on clinical experience, the child's condition, and drug availability, potential selection bias existed. To control for baseline confounding, propensity scores were estimated by multivariable logistic regression including all prespecified covariates, and 1:1 nearest-neighbour propensity score matching (PSM) without replacement was performed on the logit of the propensity score with a prespecified caliper of 0.05 [19]. Covariates included in the matching model were sex, age, body weight, ASA class, hernia type (unilateral/bilateral), surgical approach (single-port/multi-port), and operative duration. Covariate balance before and after matching was assessed using standardised mean differences (SMDs), with an absolute SMD <0.1 considered indicative of good balance. Small residual imbalances were evaluated descriptively rather than treated as exclusion criteria.

2.4 Perioperative Management and Anaesthetic Regimen

Induction and maintenance: Fentanyl and vecuronium were administered concomitantly in both groups. The remimazolam group received remimazolam (Jiangsu Hengrui; 20 mg/2 mL) for induction and maintenance; the propofol group received propofol (AstraZeneca; 20 mL/0.2 g). In both groups, bispectral index (BIS) values of 40–60 were used as the reference for anaesthetic depth, and the anaesthetic agent was discontinued 10 minutes before the end of surgery. Specific induction loading doses, maintenance infusion rates, and body-weight-stratified subgroup dosing are detailed in Additional file 1 Table S1.

Surgical technique: Standard laparoscopic high ligation of the hernia sac was performed, with pneumoperitoneum pressure of 6–8 mmHg and the child positioned in 15°–30° Trendelenburg. Detailed distributions of surgical parametres are provided in Additional file 1 Table S2.

Postoperative analgesia: Per routine clinical practice, oral acetaminophen (10–15 mg/kg) was administered when the FLACC score was ≥4 [20]. The analgesic regimen was not a study intervention but reflected real-world exposure; utilisation rates and dosing in both groups are detailed in Additional file 1 Table S2.

2.5 Outcome Measures and Assessment Methods

Study outcomes were organised into four domains: perioperative course, early postoperative recovery, safety, and health-related quality of life.

2.5.1 Anaesthesia-Related Time Parametres

The following time parametres were extracted from the anaesthesia information system, combining automated recording with manual verification. Anaesthesia induction time was defined as the interval from the start of drug infusion to the point at which BIS decreased to 40–60 and the eyelash reflex disappeared (minutes), reflecting the onset speed of the anaesthetic agent. Emergence time was defined as the interval from the end of surgery to eye opening and the ability to follow simple commands (e.g., “hold my hand,” “open your eyes”). Airway-device removal time was defined as the interval from the end of surgery to successful removal of the endotracheal tube or laryngeal mask airway. PACU stay time was defined as the interval from airway-device removal to a modified Aldrete score ≥9, meeting criteria for discharge from the post-anaesthesia care unit [21]; this measure directly reflects the quality of anaesthetic emergence and PACU turnover efficiency, serving as a surrogate indicator of perioperative healthcare resource

utilisation. All time data were retrospectively extracted from the electronic anaesthesia record system, recorded to the nearest minute.

2.5.2 Intraoperative Haemodynamic Parametres

Heart rate (HR, beats/min) and mean arterial pressure (MAP, mmHg) were continuously monitored and recorded at five predefined time points through the anaesthesia information system: before induction (T0, baseline), 1 minute after induction (T1), 1 minute after airway device placement (T2), 5 minutes after pneumoperitoneum establishment (T3), and at the end of surgery (T4, approximately 10 minutes after drug discontinuation). HR and MAP values at each predefined time point were compared between the two groups. The incidence of intraoperative haemodynamic instability was also recorded, defined as HR <60 or >140 beats/min, or MAP <50 or >100 mmHg, persisting for ≥30 seconds. Intraoperative haemodynamic stability is a key determinant of reduced perioperative organ injury, particularly in children with limited cardiovascular regulatory capacity, and serves as a core measure of anaesthetic safety and tolerability [22].

2.5.3 Early Postoperative Recovery and Healthcare Resource Utilisation

The following data were retrospectively extracted from the electronic medical record and nursing documentation:

Time to first postoperative oral intake: the interval from the end of surgery to voluntary intake of liquid or semi-liquid food (hours), reflecting the speed of postoperative gastrointestinal recovery.

Time to first postoperative ambulation: the interval from the end of surgery to independent walking of ≥5 metres, with or without assistance (hours), reflecting overall functional recovery and restoration of autonomous activity.

Length of hospital stay: total days from admission to discharge. Length of stay is a core surrogate indicator of paediatric bed turnover efficiency and a key parameter of healthcare resource

utilisation. In settings where paediatric beds are limited, shorter length of stay allows finite resources to serve more children, carrying clear health-economic and public health management implications [23].

Proportion of children meeting day-surgery discharge criteria but experiencing delayed discharge for anaesthesia-related reasons: the proportion of children who met criteria for day-surgery discharge but remained hospitalized because of anaesthesia-related factors (e.g., drowsiness, nausea/vomiting, inadequate pain control). This indicator directly reflects the impact of the anaesthetic regimen on the feasibility of a day-surgery model and serves as a Additional file 1 measure of care-process efficiency, derived from nursing assessments of discharge readiness.

Seven-day postoperative readmission rate: the proportion of children with unplanned readmission within 7 days of discharge for surgery- or anaesthesia-related complications. This is a recognised indicator of safety and quality of care in paediatric surgical patients, derived from electronic medical record face sheets and follow-up records.

2.5.4 Safety Indicators

Safety indicators comprised hepatic and renal function laboratory testing and adverse events within 24 hours postoperatively.

For hepatic and renal function, peripheral venous blood samples were obtained 1 day before surgery and 24 hours after surgery to measure alanine aminotransferase (ALT, U/L), aspartate aminotransferase (AST, U/L), serum creatinine (μmol/L), and blood urea nitrogen (BUN, mmol/L); all assays were performed by the hospital clinical laboratory according to standard protocols to evaluate the effects of the two anaesthetic regimens on hepatic and renal function. Given that hepatic and renal function are not yet fully mature in children, this domain represents a core focus of anaesthetic safety assessment.

For adverse events within 24 hours postoperatively, PACU and ward nurses continuously monitored and recorded the following: postoperative emergence agitation (Pediatric Anesthesia Emergence Delirium [PAED] score ≥10) [24,25]; nausea/vomiting (any nausea, retching, or vomiting within 24 hours postoperatively); respiratory depression (SpO_2 <90% for ≥1 minute); dizziness (child-reported dizziness or difficulty with balance); pruritus (child-reported itching or scratching behaviour); and incisional pain (FLACC score ≥4) [20,26].

The overall incidence of adverse events within 24 hours postoperatively was defined as the proportion of children in each group experiencing at least one adverse event. If a child experienced more than one type of adverse event, this was counted only once toward the overall incidence; individual adverse event categories were reported separately according to their actual occurrence. The timing, duration, and clinical management of each adverse event (e.g., administration of antiemetics, analgesics, or flumazenil) were also recorded. Intraoperative and postoperative serious adverse events were graded according to Common Terminology Criteria for Adverse Events (CTCAE) version 5.0, and events ≥grade 3 were reported separately. Detailed operational definitions and assessment tools are provided in Additional file 1 Table S3.

2.5.5 Health-Related Quality of Life

Health-related quality of life (HRQoL) was assessed using the Pediatric Quality of Life Inventory (PedsQL) 4.0 Generic Core Scales [27], an internationally recognised instrument with well-established reliability and validity that is widely used in paediatric populations. The scale comprises 23 items across four domains: physical functioning (8 items), emotional functioning (5 items), social functioning (5 items), and school functioning (5 items).

The PedsQL 4.0 Generic Core Scales provide age-appropriate versions according to developmental level: children aged 3–4 years were assessed using the parent-proxy report (Toddler

version); children aged 5–7 years were assessed using both a young-child self-report, employing a simplified 3-point Likert scale with a happy–sad faces format to aid comprehension, and a parent-proxy report (Young Child version); children aged 8–12 years were assessed using a 5-point Likert self-report together with a parent-proxy report (Child version). Item content is largely consistent across versions, with developmental adaptations mainly in wording and response format. In this study, the age-appropriate version was administered according to each child's actual age; consequently, the 3–6-year subgroup included both the Toddler version (ages 3–4) and the Young Child version (ages 5–6), and the 7–12-year subgroup included both the Young Child version (age 7) and the Child version (ages 8–12). The resulting difference in response format (3-point vs. 5-point) was taken into account in subgroup analyses.

Raw scores were linearly transformed to a 0–100 scale, with higher scores indicating better quality of life. Domain scores were calculated as the sum of item scores divided by the number of items in that domain; the total score was calculated as the sum of all item scores divided by the total number of items. Assessments were performed 1 day before surgery (baseline), 1 week after surgery, and 1 month after surgery. Data were collected by uniformly trained research nurses using standardised instructions, through face-to-face interviews to assist children and their primary caregivers in completing the scale: for children aged 3–4 years, caregivers completed the parent-proxy report; children aged 5–7 years completed the self-report (3-point scale) with researcher assistance, while caregivers concurrently completed the parent-proxy report; children aged 8–12 years completed the self-report (5-point scale) with caregiver assistance. All data were entered into the postoperative follow-up database.

From a public health perspective, HRQoL is a core outcome for evaluating the overall effect of a medical intervention, extending beyond the traditional framework of “absence of complications”

or “survival.” In paediatric populations, the speed and multidimensional pattern of postoperative quality-of-life recovery—particularly in the emotional and social functioning domains—reflect a child's psychological adaptation and overall return to normal life and school, offering irreplaceable value for assessing the long-term health benefit of perioperative management strategies [28]. In this study, the minimal clinically important difference (MCID) for PedsQL domain scores was set at 4.5 points based on prior literature.

2.6 Data Sources and Quality Control

Outcome data were derived from three sources: the hospital electronic medical record system (HIS; baseline data, surgical information, length of stay, hepatic and renal function results), the anaesthesia information management system (AIMS; anaesthesia induction and recovery times, intraoperative haemodynamic parametres, anaesthetic drug dosing), and the postoperative follow-up database (adverse event records, PedsQL scores). All data were independently extracted and cross-checked by two researchers; cases with missing data for key variables exceeding 20% were excluded. Data extractors were blinded to group assignment during extraction (data were extracted by medical record number only, with group information merged at a later stage) to ensure data accuracy and reliability.

2.7 Study Population and Final Sample Size

A total of 312 children were screened for eligibility during the study period. After applying the predefined inclusion and exclusion criteria, 63 children were excluded, leaving 249 children for propensity score matching (129 in the remimazolam group and 120 in the propofol group). After 1:1 nearest-neighbour matching with a caliper of 0.05, 120 matched pairs (240 children) were included in the final analysis; 9 children in the remimazolam group could not be matched and were

therefore excluded from all subsequent analyses. The screening and matching process is shown in Figure 1.

2.8 Statistical Analysis

Data were analysed using SPSS 26.0 and R 4.2.0. Propensity score matching was performed using the MatchIt package in R, with 1:1 nearest-neighbour matching and a caliper of 0.05. Covariate balance before and after matching was assessed using standardised mean differences (SMDs), with an absolute SMD <0.1 considered indicative of good balance. Residual imbalance was evaluated descriptively rather than using statistical significance tests. The primary outcome was emergence time; secondary outcomes included airway-device removal time, PACU stay time, intraoperative haemodynamic instability, time to first oral intake, time to first ambulation, length of hospital stay, hepatic and renal function, adverse events within 24 h, and PedsQL 4.0 scores.

After matching, continuous variables were assessed for distributional characteristics. Normally distributed continuous variables were expressed as mean ± standard deviation and compared between groups using the independent-samples t-test. Non-normally distributed continuous variables were expressed as median (interquartile range) and compared using the Mann–Whitney U test. Categorical variables were expressed as counts (%) and compared using the Pearson chi-square test or Fisher's exact test, as appropriate. Ordinal variables were compared using the Mann–Whitney U test. A linear mixed-effects model was fitted to the PedsQL scores, with group, time and group × time interaction as fixed effects and a random intercept for each child, and model estimates were reported as between-group differences with 95% confidence intervals. Bonferroni correction was applied for multiple comparisons across PedsQL domains and time points. All tests were two-sided, and $P < 0.05$ was considered statistically significant.

3 Results

3.1 Baseline Characteristics

A total of 312 children were screened for eligibility during the study period. After applying the inclusion and exclusion criteria, 63 children were excluded, and 249 children (129 in the remimazolam group, 120 in the propofol group) entered the propensity score matching process. After 1:1 nearest-neighbour matching (caliper = 0.05), 120 children in each group were successfully matched and analysed. Of the 312 children screened, 249 (79.8%) entered propensity score matching, and 240 (76.9%) were included in the final analysis. The screening and matching process, including the reasons for exclusion and the numbers excluded at each stage, is shown in Figure 1.

After matching, there were no statistically significant between-group differences in sex, age, body weight, ASA class, hernia type, surgical approach, or operative duration (all $P > 0.05$). Most covariates had standardised mean differences (SMDs) below 0.1, although small residual imbalances were observed for age (SMD = 0.127) and body weight (SMD = 0.150). Because the absolute SMDs for age and body weight exceeded the prespecified balance threshold of 0.10, residual imbalance in these variables cannot be excluded, and outcomes potentially related to age or body weight should be interpreted with caution (Table 1).

Table 1 Comparison of Baseline Data Between the Two Groups of Paediatric Patients

Indicator	Remimazolam Group (n=120)	Propofol Group (n=120)	P Value	SMD
Sex (Male/Female, n)	98/22	95/25	0.644	0.062
Age (years)	6.7±2.4	7.0±2.3	0.371	0.127
Subgroup 3–6 y (n, %)	56 (46.7)	64 (53.3)	0.356	0.132
Subgroup 7–12 y (n, %)	64 (53.3)	56 (46.7)	0.356	0.132

Indicator	Remimazolam Group (n=120)	Propofol Group (n=120)	P Value	SMD
Body weight (kg)	24.3±5.9	25.2±6.1	0.332	0.150
Body-weight subgroup (n, %)			0.683	0.081
12–20 kg	42 (35.0)	39 (32.5)		
21–30 kg	51 (42.5)	54 (45.0)		
31–40 kg	27 (22.5)	27 (22.5)		
ASA class (I/II, n)	86/34	82/38	0.546	0.074
Hernia type (unilateral/bilateral, n)	105/15	102/18	0.542	0.077
Laparoscopic approach (n, %)			0.518	0.088
Single-port	72 (60.0)	67 (55.8)		
Multi-port	48 (40.0)	53 (44.2)		
Operative duration (min)	32.8±8.7	33.2±9.0	0.745	0.045

3.2 Anaesthesia Induction and Emergence

Anaesthesia induction, emergence, and airway-device removal parametres were retrospectively extracted from the anaesthesia information system for both groups. Median anaesthesia induction time was 2.1 min (Q1, Q3: 1.8, 2.4) in the remimazolam group and 2.3 min (2.0, 2.6) in the propofol group, with no significant between-group difference ($P = 0.068$). Emergence time was 11.5 min (8.2, 14.6) in the remimazolam group, significantly shorter than the 18.2 min (14.5, 22.3) in the propofol group, with a median between-group difference of 6.7 min ($P < 0.001$). Airway-device removal time was 13.2 min (9.8, 16.5) in the remimazolam group, significantly shorter than

the 20.4 min (16.1, 24.8) in the propofol group, with a median between-group difference of 7.2 min ($P < 0.001$). PACU stay time was 25.6 min (20.4, 31.8) in the remimazolam group and 28.3 min (22.5, 34.6) in the propofol group, a difference that was not statistically significant ($P = 0.126$) (Table 2).

Table 2 Comparison of Anaesthesia Induction and Recovery Indicators Between the Two Groups (Median [Q1, Q3])

Indicator	Remimazolam Group (n=120)	Propofol Group (n=120)	P Value
Anaesthesia induction time (min)	2.1 (1.8, 2.4)	2.3 (2.0, 2.6)	0.068
Emergence time (min)	11.5 (8.2, 14.6)	18.2 (14.5, 22.3)	<0.001
Airway-device removal time (min)	13.2 (9.8, 16.5)	20.4 (16.1, 24.8)	<0.001
PACU stay time (min)	25.6 (20.4, 31.8)	28.3 (22.5, 34.6)	0.126

Note: *Data are expressed as median (interquartile range) and compared using the Mann–Whitney U test; $P < 0.05$ was considered statistically significant.*

3.3 Intraoperative Haemodynamics

Baseline HR and MAP before induction did not differ significantly between groups ($P > 0.05$). After induction, HR at T1 was 78 beats/min (70, 86) in the remimazolam group versus 74 beats/min (66, 82) in the propofol group, with a significant between-group difference ($P = 0.032$); at T2, HR was 81 beats/min (73, 89) versus 77 beats/min (69, 85), also showing a significant between-group difference ($P = 0.041$). For MAP, values at T1 were 68 mmHg (62, 74) in the remimazolam group versus 64 mmHg (58, 70) in the propofol group ($P = 0.015$); at T2, MAP was 70 mmHg (64, 76) versus 66 mmHg (60, 72) ($P = 0.023$). No significant between-group differences in HR or MAP were observed at T3 or T4 ($P > 0.05$). The incidence of intraoperative haemodynamic instability

was 15.0% (18/120) in the remimazolam group, significantly lower than the 25.8% (31/120) observed in the propofol group (P = 0.034) (Table 3).

Table 3 Comparison of Heart Rate and Mean Arterial Pressure at Different Intraoperative Time Points Between the Two Groups

Indicator	Time Point	Remimazolam Group (n=120)	Propofol Group (n=120)	P Value
HR (beats/min)	T0	86 (78, 94)	88 (80, 96)	0.321
	T1	78 (70, 86)	74 (66, 82)	0.032
	T2	81 (73, 89)	77 (69, 85)	0.041
	T3	84 (76, 92)	82 (74, 90)	0.258
	T4	82 (74, 90)	80 (72, 88)	0.306
MAP (mmHg)	T0	76 (70, 82)	75 (69, 81)	0.418
	T1	68 (62, 74)	64 (58, 70)	0.015
	T2	70 (64, 76)	66 (60, 72)	0.023
	T3	72 (66, 78)	70 (64, 76)	0.189
	T4	74 (68, 80)	72 (66, 78)	0.274
Intraoperative haemodynamic instability, n (%)	—	18 (15.0)	31 (25.8)	0.034

Note: *T0 = before induction; T1 = 1 min after induction; T2 = 1 min after airway establishment; T3 = 5 min after pneumoperitoneum establishment; T4 = at the end of surgery. Continuous data are expressed as median (interquartile range) and compared using the Mann–Whitney U test;*

categorical data are expressed as n (%) and compared using the chi-square test; P < 0.05 was considered statistically significant.

3.4 Early Postoperative Recovery and Healthcare Resource Efficiency

Time to first postoperative oral intake was 4.2±1.1 hours in the remimazolam group, significantly shorter than the 6.8±1.5 hours in the propofol group, a between-group difference of 2.6 hours (P < 0.001). Time to first postoperative ambulation was 6.5±1.3 hours in the remimazolam group, significantly shorter than the 9.3±1.8 hours in the propofol group, a difference of 2.8 hours (P < 0.001). Length of hospital stay was 2.8±0.6 days in the remimazolam group, significantly shorter than the 4.5±0.9 days in the propofol group, a difference of 1.7 days (P < 0.001). This difference in length of stay may reflect differences in anaesthetic recovery as well as non-anaesthetic factors such as discharge criteria, bed availability and scheduling, and should therefore not be attributed to the anaesthetic agent alone.

Subgroup analysis showed that, among children aged 3–6 years, length of stay was 2.5±0.5 days in the remimazolam group versus 4.8±0.9 days in the propofol group, a difference of 2.3 days (P < 0.001); among children aged 7–12 years, length of stay was 3.0±0.6 days versus 4.2±0.8 days, a difference of 1.2 days (P = 0.001). Between-group differences in recovery indicators were larger among younger children. The 7-day postoperative readmission rate was 0 in both groups (upper bound of the one-sample 95% CI, approximately 3.1%; n=120) (Table 4).

Table 4 Comparison of Postoperative Rehabilitation Indicators Between the Two Groups (Mean ± SD)

Indicator	Remimazolam Group (n=120)	Propofol Group (n=120)	Overall P Value	P Value (3–6 y Subgroup)	P Value (7–12 y Subgroup)
Time to first postoperative oral intake (h)	4.2±1.1	6.8±1.5	<0.001	<0.001	0.001
Time to first postoperative ambulation (h)	6.5±1.3	9.3±1.8	<0.001	<0.001	0.002
Length of hospital stay (d)	2.8±0.6	4.5±0.9	<0.001	<0.001	0.001

3.5 Safety Outcomes

3.6 Hepatic and Renal Function

Before surgery and at 24 hours postoperatively, ALT, AST, creatinine, and BUN levels in both groups remained within the normal paediatric reference range, with no statistically significant between-group differences ($P > 0.05$). Preoperative ALT was 18.6±6.2 U/L in the remimazolam group and 19.1±6.5 U/L in the propofol group ($P = 0.516$); at 24 hours postoperatively, values were 21.5±5.3 U/L and 21.9±5.8 U/L, respectively ($P = 0.574$). Preoperative AST was 20.8±6.1 U/L and 21.4±6.3 U/L ($P = 0.418$); at 24 hours postoperatively, 23.6±5.7 U/L and 24.1±6.2 U/L ($P = 0.529$). Creatinine and BUN did not differ significantly between groups at either time point ($P > 0.05$) (Additional file 1 Table S4).

3.7 Adverse Events Within 24 Hours Postoperatively

The overall incidence of adverse events within 24 hours postoperatively (i.e., the proportion of children experiencing at least one adverse event) was 8.3% (10/120) in the remimazolam group, significantly lower than the 35.8% (43/120) observed in the propofol group ($P < 0.001$).

For individual adverse event categories: the incidence of postoperative emergence agitation (PAED score ≥10) was 3.3% (4/120) in the remimazolam group versus 26.7% (32/120) in the

propofol group (P < 0.001, OR = 0.102, 95% CI: 0.035–0.297); the incidence of nausea/vomiting was 4.2% (5/120) versus 18.3% (22/120) (P < 0.001, OR = 0.203, 95% CI: 0.074–0.556). No respiratory depression occurred in the remimazolam group; one case (0.8%) occurred in the propofol group (P = 1.000). No cases of dizziness or pruritus occurred in the remimazolam group; in the propofol group, the incidence of dizziness was 3.3% (4/120) and of pruritus 1.7% (2/120), neither difference reaching statistical significance (P = 0.121 and P = 0.498, respectively) (Table 5).

Table 5 Comparison of the Incidence of Adverse Events Within 24 Hours After Surgery Between the Two Groups (n, %)

Adverse Event	Remimazolam Group (n=120), n (%)	Propofol Group (n=120), n (%)	P Value	Test	OR (95% CI)
Postoperative emergence agitation (PAED ≥10)	4 (3.3)	32 (26.7)	<0.001	χ^2 test	0.102 (0.035–0.297)
Nausea/vomiting	5 (4.2)	22 (18.3)	<0.001	χ^2 test	0.203 (0.074–0.556)
Respiratory depression	0 (0.0)	1 (0.8)	1.000	Fisher's exact	—
Dizziness	0 (0.0)	4 (3.3)	0.121	Fisher's exact	—
Pruritus	0 (0.0)	2 (1.7)	0.498	Fisher's exact	—
Overall adverse events	10 (8.3)	43 (35.8)	<0.001	χ^2 test	0.164 (0.079–0.341)

Note: *Categorical data are expressed as n (%). Fisher's exact test was used when the expected cell count was <5; otherwise the Pearson chi-square test was used. P < 0.05 was considered*

statistically significant. OR, odds ratio; CI, confidence interval; OR could not be calculated for cells with zero events and is marked "—". PAED, Pediatric Anesthesia Emergence Delirium scale. Odds ratios were calculated for the remimazolam group relative to the propofol group, with the propofol group as the reference category.

3.8 Age-Stratified Analysis

Among children aged 3–6 years, the overall adverse event rate was 7.1% (4/56) in the remimazolam group versus 39.1% (25/64) in the propofol group, an absolute between-group difference of 32.0 percentage points ($P < 0.001$). The incidence of postoperative emergence agitation was 1.8% (1/56) versus 29.7% (19/64) (OR = 0.050, 95% CI: 0.006–0.385); nausea/vomiting was 3.6% (2/56) versus 21.9% (14/64) (OR = 0.136, 95% CI: 0.029–0.632).

Among children aged 7–12 years, the overall adverse event rate was 9.4% (6/64) in the remimazolam group versus 32.1% (18/56) in the propofol group, an absolute difference of 22.7 percentage points ($\chi^2 = 9.237$, $P = 0.002$). The incidence of postoperative emergence agitation was 4.7% (3/64) versus 23.2% (13/56) (OR = 0.170, 95% CI: 0.046–0.629); nausea/vomiting was 4.7% (3/64) versus 14.3% (8/56) (OR = 0.311, 95% CI: 0.078–1.245). The observed absolute reduction in adverse events was greater in the 3–6-year subgroup than in the 7–12-year subgroup (32.0 vs. 22.7 percentage points). However, formal interaction testing was not performed (Additional file 1 Table S5).

3.9 Postoperative Health-Related Quality of Life

At baseline (1 day before surgery), there were no statistically significant between-group differences in any PedsQL 4.0 domain or total score ($P > 0.05$), confirming baseline comparability. For physical functioning, preoperative scores were 78.5±6.2 in the remimazolam group and

77.9±6.5 in the propofol group (P = 0.482). At 1 week postoperatively, physical functioning was 89.2±5.3 in the remimazolam group, significantly higher than the 81.6±5.8 in the propofol group (P < 0.001); at 1 month, scores were 92.3±4.1 and 85.7±4.6, respectively (P < 0.001). For emotional functioning, scores at 1 week were 90.5±4.8 versus 83.2±5.2 (P < 0.001); at 1 month, 93.1±3.7 versus 86.5±4.2 (P < 0.001). For social functioning, scores at 1 week were 91.3±4.5 versus 84.7±4.9 (P < 0.001); at 1 month, 94.2±3.5 versus 87.8±3.9 (P < 0.001). For school functioning, scores at 1 week were 88.6±5.1 versus 81.3±5.5 (P < 0.001); at 1 month, 91.5±4.3 versus 84.9±4.7 (P < 0.001).

For the total score, values at 1 week were 89.9±4.6 in the remimazolam group versus 82.8±5.0 in the propofol group (P < 0.001); at 1 month, 92.8±3.8 versus 86.2±4.1 (P < 0.001). Between-group differences at 1 week and 1 month postoperatively for all PedsQL domains exceeded the minimal clinically important difference (MCID = 4.5 points). Subgroup analyses showed that the remimazolam group had higher postoperative PedsQL scores than the propofol group in both age subgroups (Table 6).

Table 6 Comparison of PedsQL 4.0 Scale Scores Before and After Surgery Between the Two Groups (Mean ± SD, Points)

Indicator	Time Point	Remimazolam Group (n=120)	Propofol Group (n=120)	Overall P Value	P Value (3–6 y Subgroup)	P Value (7–12 y Subgroup)
Physical Functioning	1 d Before Surgery	78.5±6.2	77.9±6.5	0.482	0.513	0.456
	1 wk After Surgery	89.2±5.3	81.6±5.8	<0.001	<0.001	0.002

Indicator	Time Point	Remimazolam Group (n=120)	Propofol Group (n=120)	Overall P Value	P Value (3–6 y Subgroup)	P Value (7–12 y Subgroup)
Emotional Functioning	1 mo After Surgery	92.3±4.1	85.7±4.6	<0.001	<0.001	0.001
	1 d Before Surgery	80.3±5.9	79.8±6.1	0.537	0.568	0.492
	1 wk After Surgery	90.5±4.8	83.2±5.2	<0.001	<0.001	0.003
	1 mo After Surgery	93.1±3.7	86.5±4.2	<0.001	<0.001	0.002
Social Functioning	1 d Before Surgery	82.1±5.6	81.5±5.8	0.471	0.503	0.438
	1 wk After Surgery	91.3±4.5	84.7±4.9	<0.001	<0.001	0.002
	1 mo After Surgery	94.2±3.5	87.8±3.9	<0.001	<0.001	0.001
School Functioning	1 d Before Surgery	76.8±6.3	76.2±6.5	0.519	0.551	0.487
	1 wk After Surgery	88.6±5.1	81.3±5.5	<0.001	<0.001	0.003
	1 mo After Surgery	91.5±4.3	84.9±4.7	<0.001	<0.001	0.002
Total Score	1 d Before Surgery	79.4±5.8	78.8±6.0	0.493	0.525	0.461

Indicator	Time Point	Remimazolam Group (n=120)	Propofol Group (n=120)	Overall P Value	P Value (3–6 y Subgroup)	P Value (7–12 y Subgroup)
	1 wk After Surgery	89.9±4.6	82.8±5.0	<0.001	<0.001	0.002
	1 mo After Surgery	92.8±3.8	86.2±4.1	<0.001	<0.001	0.001

Note: *PedsQL, Pediatric Quality of Life Inventory; MCID, minimal clinically important difference. Between-group differences at 1 week and 1 month postoperatively all exceeded the MCID (4.5 points), indicating clinically meaningful differences. Overall P values indicate between-group comparisons in the full cohort; subgroup P values indicate between-group comparisons within each age subgroup and are not interaction P values.*

4 Discussion

4.1 Principal Findings

This retrospective cohort study compared remimazolam with propofol in children undergoing laparoscopic inguinal hernia repair after propensity score matching. Remimazolam was associated with shorter emergence and airway-device removal times, a lower incidence of intraoperative haemodynamic instability, and fewer adverse events within 24 hours after surgery, particularly emergence agitation and nausea/vomiting. Children receiving remimazolam also achieved earlier oral intake and ambulation and had a shorter length of hospital stay. In addition, PedsQL scores at 1 week and 1 month after surgery were higher in the remimazolam group, with between-group differences exceeding the reported minimal clinically important difference.

Taken together, these findings suggest that the potential advantages of remimazolam extend beyond immediate anaesthetic recovery to early postoperative functional recovery and patient-reported quality of life. However, because this was a single-centre retrospective study, these associations should be interpreted cautiously and require confirmation in prospective multicentre studies.

4.2 Comparison with Existing Evidence

The findings of this study are broadly consistent with recent literature on paediatric applications of remimazolam, while also providing incremental information across several dimensions.

With respect to postoperative emergence agitation, the incidence in this study was 3.3% in the remimazolam group versus 26.7% in the propofol group. This is highly consistent with the systematic review by Zhang et al. [22], which included 23 studies and 2,847 paediatric patients and found that remimazolam reduced the risk of emergence delirium by 61% (RR = 0.39, 95% CI 0.21–0.70). A randomised controlled trial by Cai et al. [29] similarly reported an emergence delirium incidence of 5% with continuous remimazolam infusion versus 35% with placebo among children aged 1–6 years undergoing laparoscopic surgery. Wu et al. [15] likewise found a lower incidence of emergence agitation with remimazolam (12%) than with propofol (30%) in preschool children undergoing adenotonsillectomy.

With respect to haemodynamic stability, HR and MAP were higher at selected time points after induction and airway establishment in the remimazolam group, while the incidence of intraoperative haemodynamic instability was lower (15.0% vs. 25.8%). These findings are broadly consistent with previous evidence suggesting a more stable haemodynamic profile with remimazolam than with propofol during induction of general anaesthesia [14],[30],[31].

With respect to emergence recovery, emergence time and airway-device removal time in this study were significantly shorter in the remimazolam group, by approximately 6.7 minutes and 7.2 minutes, respectively. A multicentre randomised controlled trial by Fang et al. [32] in children aged 3–6 years undergoing elective surgery similarly found a lower incidence of adverse events with remimazolam (19%) than with propofol (49%), together with shorter emergence and extubation times. Studies by Wu et al. [15] and Zhong et al. [33] reached similar conclusions. Together, these results indicate that the pharmacokinetic advantages of remimazolam—rapid metabolism by tissue esterases and a short elimination half-life (approximately 45–70 minutes)—translate effectively into clinically faster emergence and extubation [12,13].

Quality-of-life assessment represents a distinctive contribution of this study. To our knowledge, this is among the first real-world studies of remimazolam in paediatric anaesthesia to systematically evaluate postoperative quality of life using the PedsQL 4.0 scale. Howard et al. [28] previously validated the feasibility of applying PedsQL in the perioperative setting for children aged 3–12 years undergoing day surgery. In this study, PedsQL domain scores at 1 week and 1 month postoperatively were significantly higher in the remimazolam group, with differences exceeding the minimal clinically important difference (4.5 points). Improvement in quality of life reflects more than optimization of clinical indicators—it directly signifies a child's return to normal life, adaptation to returning to school, and a reduced caregiving burden on the family, which are core goals of public health intervention.

4.3 Greater Benefit Among Younger Children: Reducing Age-Related Health Inequity

The age-stratified analysis showed lower rates of adverse events in the remimazolam group in both age subgroups. The observed absolute between-group difference was larger among children aged 3–6 years than among those aged 7–12 years (32.0 vs. 22.7 percentage points). However, these

analyses were exploratory, and no formal treatment-by-age interaction test was performed; therefore, the observed difference should not be interpreted as evidence of a statistically confirmed age-dependent treatment effect.

Several pharmacological and physiological factors may contribute to the observed pattern. Younger children may have greater physiological variability and may be more vulnerable to cardiovascular effects during anaesthesia. The pharmacokinetic characteristics of remimazolam, including its rapid metabolism by tissue esterases, may be relevant to its use in paediatric patients [12] [11]. Its relatively favourable haemodynamic profile compared with propofol may also be clinically relevant during anaesthetic induction [14]. Nevertheless, these potential mechanisms remain hypothesis-generating and should be evaluated in adequately powered prospective studies with prespecified age-stratified analyses.

4.4 Health System Efficiency and Policy Implications

Length of hospital stay was shorter in the remimazolam group than in the propofol group (2.8 ± 0.6 days vs. 4.5 ± 0.9 days, $P < 0.001$). Time to first postoperative oral intake and first ambulation were also 2.6 and 2.8 hours shorter, respectively. These differences may be relevant to postoperative resource use, particularly in paediatric surgical settings where bed availability can affect the scheduling of elective procedures. However, the clinical significance of a shorter hospital stay depends on the factors determining discharge and should not be interpreted solely as an indicator of healthcare system efficiency.

Previous studies have reported similar benefits from enhanced recovery approaches in paediatric surgery. Srivatsa et al. [23] found that implementation of an ERAS pathway in paediatric surgical oncology reduced median length of stay from 4.48 to 2.87 days ($P < 0.001$). A review by Fung et al. [34] noted that ERAS implementation in paediatric surgery significantly shortens length of stay

and accelerates functional recovery. Zhu et al. [35] similarly confirmed that ERAS protocols significantly shorten length of stay in children undergoing laparoscopic surgery. Systematic reviews by Stangl-Kremser et al. [9] and Dawson-Gore et al. [10] indicate that implementation of paediatric ERAS still faces challenges, but that an increasing number of ERAS elements are being adopted overall. The advantages of remimazolam observed in this study with respect to shortening length of stay and accelerating recovery provide new evidence to inform the choice of anaesthetic agent within paediatric ERAS pathways. It should be noted that the above discussion, based on statistically significant differences in recovery indicators such as length of stay, represents inference regarding surrogate measures of health system performance. This study did not perform a formal health-economic evaluation (cost-effectiveness or cost-utility analysis); the acquisition cost of remimazolam is higher than that of propofol, and whether the reduction in bed-days and adverse events offsets the incremental drug cost requires rigorous economic evaluation.

From a clinical perspective, remimazolam may be considered as one option for anaesthesia in children undergoing short laparoscopic procedures, particularly when rapid postoperative recovery is an important consideration. The larger observed reduction in adverse events among children aged 3–6 years is of interest, but no formal treatment-by-age interaction test was performed; therefore, this finding should be regarded as exploratory rather than as evidence for age-specific treatment selection. Further prospective studies are needed to determine whether the observed reductions in recovery time and hospital stay can be reproduced under standardised discharge criteria. Multicentre studies incorporating formal cost-effectiveness analyses would also help clarify the overall clinical and economic value of remimazolam in paediatric surgery.

4.5 Limitations

This study has several limitations that should be considered when interpreting the results. (1) This was a single-centre retrospective cohort study; although propensity score matching controlled for observable confounders (e.g., age, sex, body weight, ASA class, surgical approach), unmeasured or residual confounding may remain, including preoperative psychological state, anaesthesiologist experience, family socioeconomic status, and caregiving adherence, all of which may influence postoperative recovery and quality-of-life outcomes. In addition, although most covariates were well balanced after matching, the absolute standardised mean differences for age (0.127) and body weight (0.150) remained above the prespecified threshold of 0.10, indicating residual imbalance in these variables. (2) Observations at each time point relied on routine clinical documentation rather than a uniformly and rigorously standardised study protocol; indicators such as emergence time, extubation time, PACU stay time, and follow-up timing may be subject to some degree of recording variability, and time to first oral intake and first ambulation were influenced by clinical orders and nursing guidance, rather than reflecting purely physiological recovery. (3) This study primarily included children aged 3–12 years with ASA class I–II undergoing laparoscopic inguinal hernia repair; extrapolation of these findings to other age groups, other surgical procedures, or different healthcare resource settings should be made with caution, given that anaesthetic agent selection, postoperative analgesic protocols, and PACU management practices vary across regions and institutions. (4) This study did not perform a formal cost-effectiveness or cost-utility analysis; references to “healthcare resource savings” should therefore be understood as indirect inferences based on surrogate measures such as length of stay. The acquisition cost of remimazolam is higher than that of propofol, and whether the incremental cost is offset by a corresponding incremental health benefit requires rigorous economic evaluation. (5) The follow-up period was limited. Quality-of-life follow-up in this study extended only to 1 month postoperatively, precluding

assessment of the long-term effects of remimazolam on children's cognitive development, learning ability, and psychobehavioural outcomes. Long-term neurodevelopmental safety remains an important unanswered question for paediatric use of remimazolam [22].

4.6 Future Directions

In this real-world retrospective cohort study, remimazolam anaesthesia was associated with faster early postoperative recovery, fewer episodes of intraoperative haemodynamic instability and postoperative adverse events, and higher PedsQL scores within 1 month after laparoscopic inguinal hernia repair in children. The observed benefits were present in both age subgroups, although the absolute reduction in adverse events was larger among children aged 3–6 years. Because no formal treatment-by-age interaction test was performed, this age-related difference should be considered exploratory.

These findings support further evaluation of remimazolam as an anaesthetic option for short paediatric laparoscopic procedures. Prospective multicentre randomised trials are needed to confirm these associations and to determine the optimal dosing, long-term neurodevelopmental safety, and cost-effectiveness of remimazolam in children. Longer follow-up should also assess whether the observed improvements in early postoperative quality of life persist beyond the 1-month assessment period.

5 Conclusions

In this propensity score-matched retrospective cohort study, remimazolam anaesthesia was associated with faster early recovery, greater intraoperative haemodynamic stability, fewer adverse events within 24 h postoperatively, and better health-related quality of life at 1 month after laparoscopic inguinal hernia repair in children. The observed absolute reduction in adverse events was larger among children aged 3–6 years, although no formal treatment-by-age interaction test

was performed. These findings suggest that remimazolam may be a useful anaesthetic option for short paediatric laparoscopic procedures and support further evaluation in prospective multicentre studies. Future research should also assess long-term neurodevelopmental safety, optimal dosing, and cost-effectiveness.

6 List of abbreviations

AIMS, anaesthesia information management system; ALT, alanine aminotransferase; ASA, American Society of Anesthesiologists; AST, aspartate aminotransferase; BIS, bispectral index; BUN, blood urea nitrogen; CI, confidence interval; CTCAE, Common Terminology Criteria for Adverse Events; ERAS, enhanced recovery after surgery; FLACC, Face, Legs, Activity, Cry, Consolability; HIS, hospital information system; HRQoL, health-related quality of life; IQR, interquartile range; MCID, minimal clinically important difference; OR, odds ratio; PACU, post-anaesthesia care unit; PAED, Pediatric Anesthesia Emergence Delirium; PedsQL, Pediatric Quality of Life Inventory; PSM, propensity score matching; SD, standard deviation; SMD, standardised mean difference; STROBE, Strengthening the Reporting of Observational Studies in Epidemiology.

Additional file 1

File name: Additional file 1.docx

Title: Supplementary tables S1–S5

Description: Table S1. Anaesthetic drug utilisation in the two groups. Table S2. Surgical and postoperative analgesia-related clinical data. Table S3. Operational definitions and assessment tools for adverse events. Table S4. Comparison of preoperative and 24-hour postoperative hepatic

and renal function indicators. Table S5. Incidence of adverse reactions within 24 h after surgery by age subgroup.

Format: DOCX

Figure

Figure 1. Study participant flow diagram.

Legend:

Flow of children through the study. Of 312 children screened, 63 were excluded for not meeting the inclusion criteria or meeting one or more exclusion criteria. The remaining 249 children (129 remimazolam, 120 propofol) entered 1:1 nearest-neighbour propensity score matching without replacement with a caliper of 0.05, yielding 120 matched pairs (240 children) for the final analysis; 9 children in the remimazolam group could not be matched and were excluded from all analyses.

Declarations

Ethics approval and consent to participate

This study was approved by the Ethics Committee of the First Affiliated Hospital of Henan Medical University (approval number EC-024-486). The Ethics Committee waived the requirement for written informed consent because this was a secondary analysis of de-identified routinely collected clinical records, did not alter clinical management and involved no additional biological sampling.

Clinical trial number: not applicable.

Consent for publication

Not applicable. The manuscript reports aggregate results from de-identified clinical records and contains no individual-level identifying information.

Availability of data and materials

The datasets generated and/or analysed during the current study are not publicly available due to institutional and ethical restrictions on sharing sensitive clinical information from minors, but are available from the corresponding author upon reasonable request, subject to approval by the Ethics Committee of the First Affiliated Hospital of Henan Medical University.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

JT: Conceptualization, Data curation, Formal analysis, Investigation, Writing – original draft. JL: Conceptualization, Methodology, Project administration, Supervision, Writing – review & editing. TF: Data curation, Investigation, Writing – review & editing. ZJ: Data curation, Investigation, Writing – review & editing. JS: Formal analysis, Investigation, Writing – review & editing. XL: Data curation, Investigation, Writing – review & editing. All authors contributed to the article and approved the submitted version.

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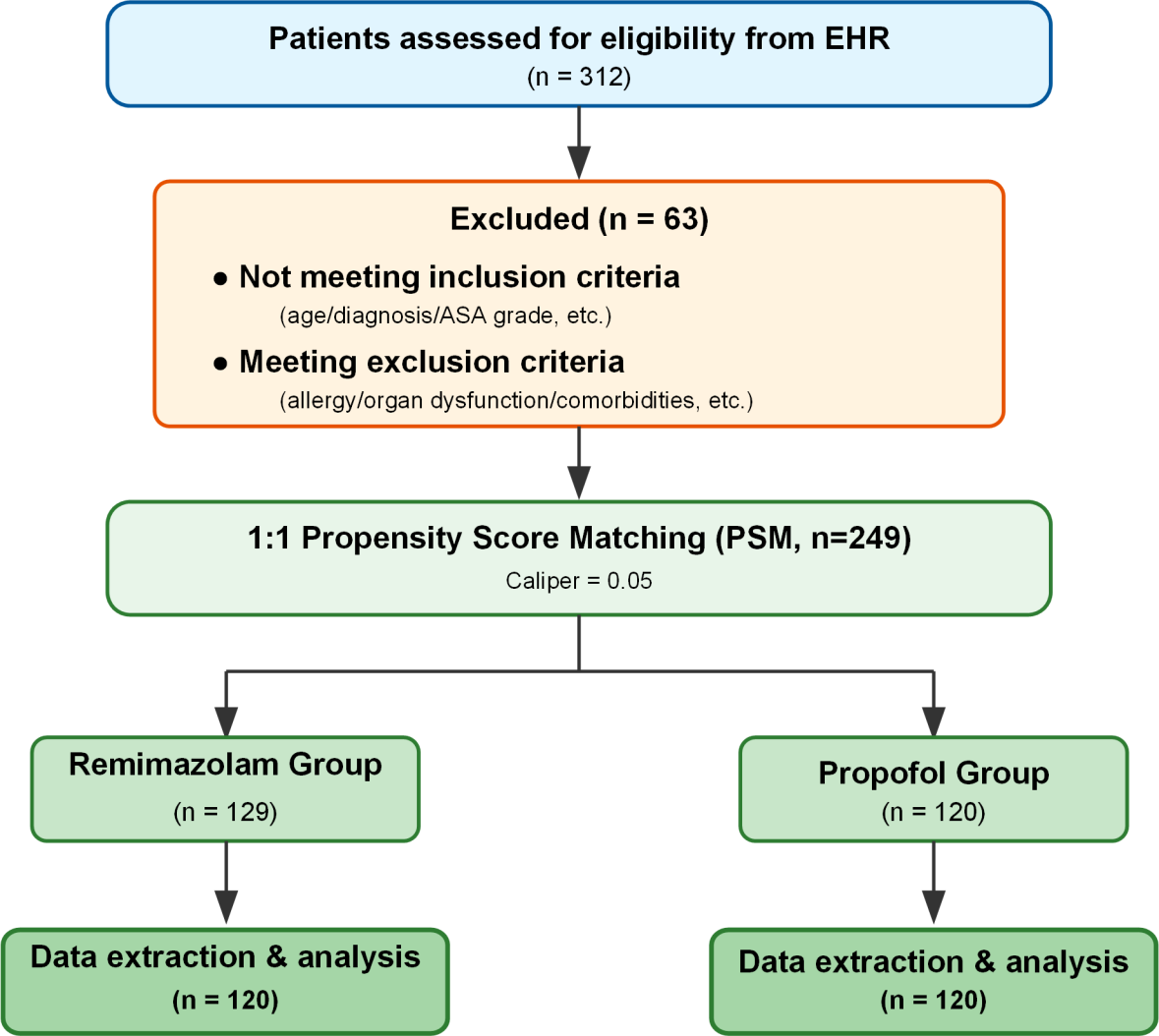
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Patients assessed for eligibility from EHR
(n = 312)
Excluded (n = 63)
• Not meeting inclusion criteria
(age/diagnosis/ASA grade, etc.)
• Meeting exclusion criteria
(allergy/organ dysfunction/comorbidities, etc.)
1:1 Propensity Score Matching (PSM, n=249)
Caliper = 0.05
Remimazolam Group
(n = 129)
Propofol Group
(n = 120)
Data extraction & analysis
(n = 120)
Data extraction & analysis
(n = 120)

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