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Perioperative Modulation of Recovery Kinetics and Analgesic Efficiency in Minimally Invasive Abdominal Surgery

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ABSTRACT

Background: The use of perioperative analgesic interventions in addition to opioid dose reduction has an impact on postoperative recovery in minimally invasive abdominal surgery. Measuring recovery dynamics and analgesic performance gives a systems perspective of postoperative time courses as opposed to drug comparison. **Methods**: Perioperative data on 300 adult patients, in the Department of Anaesthesia, Fatima Memorial Hospital, Lahore, Pakistan, undergoing the abdominal less invasive surgeries were included in this secondary analytical study. The recovery kinetics were evaluated based on time-dependent outcomes as long as extubation latency, early postoperative pain slope and accumulated opioid exposure divided by pain burden. A combination of opioid intake and 24 hours serial pain assessment was used to create an Analgesic Efficiency Score (AES). The patients were stratified to high- and low-efficiency recovery profiles. Determinants of the accelerated recovery were analyzed using multivariate regression and recovery curve modeling. **Results**: High-efficiency recovery patients had significantly lower opioid-to-pain ratios (0.42 ± 0.11 vs. 0.61 ± 0.15, $p < 0.001$) and followed faster early recovery kinetics, which involve fewer extubation latency differences (mean difference -1.9-minutes, $p<0.001$). The relationship between the intensity of pain and pain resolution after surgery in efficient recovery was steeper with a higher decrease in the level of pain during the initial 24 hours after surgery. Multivariate analysis found that the analgesic efficiency was an independent predictor of faster recovery kinetics (adjusted $R^2 = 0.38$) regardless of the demographics or the duration of the surgery. **Conclusion**: Secondary recovery-oriented analysis proves that analgesic efficiency with opioid reduction is a major determinant of postoperative kinetics of recoveries in the case of minimally invasive abdominal surgery. This model of recovery-trajectory provides a new strategy of perioperative optimization beyond traditional comparative anesthetic research.

Keywords: Post-operative Period, Analgesics, Opioid, Recovery of Function, Laparoscopy, Anesthesia, General Pain Measurement, Enhanced Recovery After Surgery (ERAS) Protocols

Introduction

Minimal invasive abdominal surgery has revolutionized the concept of perioperative care by minimizing tissue trauma, shortening of hospitalization and hastening functional recovery [1]. These benefits do not exclude the fact that postoperative pain and opioid use is still a major issue, which tends to slow down the process of mobilization and expose the patient to the risk of opioid adverse effects [2]. Optimization of perioperative analgesic regimens is thus considered as a primary goal in contemporary anesthesia and surgical rehabilitation. Perioperative recovery kinetics is a multidimensional construct that includes time to extubate patients, early neurologic recovery, pain management, radiologic stability, and discharge-preparedness after post-anesthesia care units [3,4]. There is growing evidence these outcomes are not only affected by method of surgery but also by molecular and neurophysiological regulation during anesthesia [5]. Anti-inflammatory, neuroprotective, and opioid-sparing anti-inflammatory-based agents might play significant role in improving recovery patterns other than conventional analgesia.

According to the therapeutic values, neo-operative pharmacologic modulation can modify nociceptive pathways, stress reactions, and central sensitization thus enhancing analgesic efficacy with minimal opioid exposure [6,7]. The change is congruent with the principles of enhanced recovery after surgery (ERAS) strategy, which focuses on multimodal, mechanism-based approaches to maximize the outcome of the postoperative phase [8]. Nevertheless, comparative effectiveness data emphasizing recovery kinetics instead of pain scores alone are very limited, especially when it comes to minimally invasive procedures. Secondary and exploratory analysis of perioperative data offer the prospect of analyzing the dynamics of recovery by other analytical prisms, including the analgesic efficiency index, modelling of recovery time and multivariate predictors of early postoperative performance [9]. These methods can be used to learn more about the effects of perioperative interventions on functional recovery instead of single clinical outcomes.

The current study compares the perioperative strategies in minimally invasive abdominal surgery by applying secondary statistical intra-analyses to assess recovery kinetics and analgesic efficacy. This study contributes to the novel paradigm of precision perioperative therapeutics and evidence-based optimization of the anesthetic practice by focusing on recovery-oriented outcomes.

Methodology

Minimal invasive abdominal surgery has revolutionized the concept of perioperative care by minimizing tissue trauma, shortening of The secondary analysis was carried out to identify the perioperative recovery kinetics and analgesic effectiveness in patients with minimal abdominal surgery under general anaesthesia based on the available clinical data at Fatima Memorial Hospital, Lahore, collected between September 2024 to February 2025 (vide letter no. FMH-26/04/2024-1RB-1396, dated August 22, 2024). The research study was planned as a non-duplicative study of earlier perioperative records gathered. Institutional research governance policies granted ethical compliance on the secondary use of anonymized patient data, and all patient identifiers were stripped off beforehand.

Non-probability consecutive sampling was used to select a total of 300 patient records. OpenEpi version 3.0.0 (released 2013, Atlanta, GA, USA) was used to calculate the required sample size on a finite population of 300 patients with 95% confidence interval (CI) and a 5% margin of error, where full documentation of perioperative, including analgesic use, recovery parameters, and postoperative follow-up data was required [10]. The criteria of the study were adult patients (18-60 years), either gender with American Society of Anesthesiologists (ASA) physical status I-II, and had undergone voluntary laparoscopic surgeries. The cases that had missing information were excluded [11]. Data on the age, sex, body mass index, ASA classification, and surgical indication were displayed as baseline variables. The patients were stratified based on the intraoperative pharmacological modulation strategy used. Recovery-centered domains were used to rearrange outcome variables. The major outcomes were the amount of opioid used in the first 24 hours of operation, the duration of time to extubation, the postoperative pain initially, and the length of stay at the post-anesthesia care unit (PACU). The measurement of analgesic efficiency was made based on opioid-sparing indexes and opioid utilization ratio adjusted by pain. The secondary outcomes were the incidence of postoperative nausea and vomiting (PONV) and hemodynamic variability during the recovery.

The SPSS version 26.0 (IBM Corp., Armonk, NY) was used to analyze the data [12]. Continuous variables were checked against normality by the ShapiroWilk test and indicated as mean ± standard deviation or median-interquartile range, according to the type of data. Comparative analysis between groups of statistics were conducted with independent t-tests or MannWhitney U tests in the event of continuous data and Chi-square tests in the case of categorical data. The independent predictors of faster recovery and less intensive opioid requirement were identified by means of multivariate regression modeling. A p-value of less than 0.05 was taken as statistically significant.

Results

The sample size in this secondary analysis of recovery and analgesic performance after minimum invasive abdominal surgery comprised 300 patients. Patients that were more efficient at analgesia took shorter extubation times, earlier analgesic demands and Post-Anesthesia Care Unit (PACU) stay. Opioid normalized pain scales showed a significantly less oppression in pain with a decreased opioid intake. The effect of analgesic efficiency on accelerated recovery was established as an independent predictor, which is more significant than the effects of age, sex, and length of operation. These results indicate that perioperative modulation systems are important in ensuring the success of recovery kinetics and analgesic effects. Table 1 indicates that recovery kinetics was expedited among patients that had optimised perioperative modulation.

Table 1. Recovery Kinetics and Early Postoperative Efficiency Profiles

Parameter	High-Efficiency Recovery (n=152)	Low-Efficiency Recovery (n=148)	MD	p-value
Extubation latency (minutes, mean ± SD)	8.9 ± 2.0	10.8 ± 2.5	−1.9	<0.001
Time to first analgesic request (min)	54.6 ± 14.2	39.8 ± 12.9	+14.8	<0.001
PACU stay duration (min)	41.2 ± 7.9	45.6 ± 8.8	−4.4	0.003
Pain score at 6 hours (NRS)	3.1 ± 0.8	3.9 ± 0.9	−0.8	<0.001
Pain score at 24 hours (NRS)	2.4 ± 0.7	3.2 ± 0.8	−0.8	<0.001
SD = Standard Deviation, PACU = Post-Anesthesia Care Unit, NRS = Numeric Rating Scale, MD = Mean Difference, p = Significance Value				

Patients in high-efficiency recovery group (n = 152) had relatively faster extubation (8.9 ± 2.0 vs. 10.8 ± 2.5 min, p < 0.001), increased time to first analgesic request (54.6 ± 14.2 vs. 39.8 ± 12.9 min, p < 0.001), and shorter PACU stay (41.2 ± 7.9 vs. 45.6 ± 8.8 min, p =

0.003) as compared to the low-efficiency recovery group (n = 148). Faster recovery and improved postoperative pain control in the high-efficiency group was observed in terms of pain scores which were lower at 6 hours (3.1 ± 0.8 vs. 3.9 ± 0.9, p < 0.001) and further reduced after 24 hours postoperatively (2.4 ± 0.7 vs. 3.2 ± 0.8, p < 0.001). The optimization of perioperative modulation was observed as high-efficacy analgesic patients exhibited better pain-controlled and recovery kinetics. Table 2 compares the performance of high and low-efficiency groups on analgesic efficiency.

Table 2. Analgesic Efficiency Metrics and Opioid–Pain Normalization

Variable	High-Efficiency Group	Low-Efficiency Group	p-value
Total 24-h opioid consumption (mg MME)	11.8 ± 3.9	16.4 ± 4.6	<0.001
Cumulative pain burden (AUC_{0-24})	62.3 ± 9.5	71.8 ± 10.2	<0.001
Opioid-to-pain ratio	0.42 ± 0.11	0.61 ± 0.15	<0.001
Analgesic Efficiency Score (AES)	78.6 ± 8.9	62.1 ± 9.4	<0.001
Patients achieving AES ≥75 (%)	68.4%	21.6%	<0.001

AES = Analgesic Efficiency Score, MME = Morphine Milligram Equivalents, AUC0-24 = Area under curve over the last 24h, p = Significance Value

Although the mean pain scores were lower at 24 hours (11.8 ± 3.9 vs. 16.4 ± 4.6 mg MME, p < 0.001), and cumulative pain burden (AUC0-24: 62.3 -9.5 vs. 71.8 -10.2, p <0.001) was observed in the high-efficiency vs. the low-efficiency group, a decreased opioid to pain ratio (0.42 + 0.11 vs. 0.61 + 0.15, p < 0.001) and increased Analgesic Efficiency Score (AES: 78.6 + 8.9 vs. 62.1 + 9.4, p < 0.001) were observed in the study population. It is worth noting that 68.4% of patients in high-efficiency group had an AES 75 or higher, whereas 21.6% in the low-efficiency group had the same, that is, their analgesic effect and pain management were improved (p = 0.001). Table 3 shows multivariate predictors for of accelerated recovery kinetics in the study population.

Table 3. Multivariate Predictors of Accelerated Recovery Kinetics

Predictor Variable	β Coefficient	95% CI	p-value
Analgesic Efficiency Score	−0.48	−0.61 to −0.35	<0.001
Operative duration (minutes)	0.12	0.03 to 0.21	0.009
Age (years)	0.05	−0.02 to 0.12	0.14
Sex (female vs male)	−0.07	−0.18 to 0.04	0.21
BMI (kg/m²)	0.09	0.01 to 0.17	0.03

n = Number of participants, BMI = Body Mass Index, p = Significance value, CI = Confidence Interval

Faster recovery was significantly connected with higher analgesic efficiency score (β = -0.48; -0.61 to -0.35; p = 0.001). Slower recovery was associated with longer operative time (β = 0.12; 95% CI: 0.03 -0.21; p =.009) and greater BMI (β = 0.09; 95% CI: 0.01 -0.17; p =.03), whereas age (β = 0.05; 95% CI: -0.02 -0.12; p =0.14) and sex (β = -0.07; 95% CI: -0.018-0.04; p = 0.21) were not potential indicators. The predictors of accelerating postoperative kinetics of recovery are independent of demographics and procedure variables and are predicted by analgesic efficiency. The model explained 38% of recovery variability (adjusted $R^2 = 0.38$).

Discussion

This study aimed at assessing the effect of perioperative modulation interventions on recovery dynamics and analgesia efficacy in patients undergoing abdominal abbreviated surgeries under general anesthesia. The results suggest that increased analgesic performance is closely linked with rapid extubation, shorter PACU experience, delayed requirement of rescue analgesia and the need to reduce cumulative opioid intake and findings show the necessity of optimized perioperative measures in the achievement of functional recovery. Patients with high analgesic efficiency would have a much lower pain score at 6 and 24 hours after surgery although taking less opioid medication, which implies better pain opioid balance. These findings are consistent with the existing literature which showed that opioid-sparing approaches to the perioperative analgesic regimen, along with attempts to optimize early recovery outcomes, enhance the magnitude of the postoperative pain burden in laparoscopic and minimally invasive surgeries [13,14]. As assessed using AES, analgesic efficiency was found to be the most significant independent variable predictor of faster recovery in the multivariate analysis compared with age, sex and operative time [15,16]. This observation is aligned with the literature on the significance of functional indices of analgesia as opposed to general opioid use as a better indicator of early recovery [17,18].

This paper also revealed that procedural variables, namely, the length of operation and the body mass index of a patient played a humble role in recovery kinetics, but demographic factors such as age and sex were not a significant predictor variable [19]. This confirms earlier studies that early postoperative recovery patterns are largely determined by perioperative physiological optimization, but not patient features themselves [20]. Normalization of opioid use to pain load gives a subtle insight into analgesic efficacy and supportive care of AES as a method to inform the formulation of individualized perioperative analgesic plans [21]. The strategy of perioperative modulation may enhance the recovery by reducing the adverse effects of opioids, improving the stability of the hemodynamics, and promoting early mobilization [22]. These results align with the literature stating that multimodal pain management methods and especially those with focus on opioid-sparing treatments ease the preparation to discharge earlier and enhance patient satisfaction without endangering patient safety [23,24]. Notably, the recent analysis further shows that AES can serve as an effective parameter concerning identifying patients with the highest potential to take advantage of individualized analgesic treatments, which foster accuracy in perioperative treatment [25].

This study has several limitations such as, being a retrospective, secondary analysis, rules out the element of randomisation, and can have selection bias although there is non-duplication of records that bleed into the study twice since the study is non-randomised. The confounding variables like changes in perioperative fluids, anesthetic technique and non-reported adjunct analgesic were not fully defined. Also, the study is single-centered and could not be generalized to other institutions that had different perioperative protocols. The future research ought to involve multicenter, prospective, randomized designs, with subsequent follow up of sustained postoperative pain and functional recovery and research biomarker-based or patient-specific analgesic modulation to narrow down optimization of early recovery.

Conclusion

This study shows a significant relationship between perioperative modulation leading to high analgesic efficacies, faster recovery dynamics, decreased cumulative opioid use, and decreased early postoperative pain in patients receiving minimally invasive abdominal surgeries. AES is an independent and a strong predictor of early recovery which is stronger than the effects of demographic and procedural factors. The conclusions illuminate clinical significance of combining patient-focused, opioid-saving perioperative approaches, so as to maximize recovery, opioid-associated complication reduction, and improve patient outcomes. Implementation of AES-led analgesic guidelines can help to support accuracy during perioperative care and especially during ERAS pathways. Future studies ought to be multicenter, prospective studies assessing long-term recovery, persistent postsurgical pain as well as individualized analysis of analgesics such as multimodal and biomarker-based.

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Conflict of Interest

None

Authors' Contribution

AS, MAK conceived the idea and designed the research work, AS did data analysis, manuscript writing, AS, MAS did proof read and editing, All authors provided final approval and agreed to be accountable for all aspects of research.

Ethical Statement

This cross-sectional study was conducted at the Department of Anaesthesia, Fatima Memorial Hospital, over six months from September 2024 to February 2025 (Ref: FMH-26/04/2024-1RB-1396).

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