Journal of Comprehensive Surgery

Original Article

DOI: 10.51271/JOCS-0059

The effects of analgesia methods on postoperative diaphragm muscle contraction in patients undergoing laparotomy

Fethi Gültop[1], Gaye Şensöz Çelik[2]

[1]Department of Anestesiology and Reanimation, Ankara Etlik City Hospital, Ankara, Turkiye

[2]Departmant of Intensive Care Medicine, Addenbrooke's Hospital, Cambridge University Hospitals NHS, Cambridge, United Kingdom

Cite this article as: Gültop F, Şensöz Çelik G. The effects of analgesia methods on postoperative diaphragm muscle contraction in patients undergoing laparotomy. *J Compr Surg.* 2025;3(3):53-58.

Received: 30.07.2025 ◆ **Accepted**: 20.08.2025 ◆ **Published**: 29.08.2025

ABSTRACT

Aims: This prospective observational study aimed to evaluate the effects of different postoperative analgesia methods on diaphragm thickening fractions in patients undergoing major elective abdominal surgery.

Methods: Sixty-six adult patients scheduled for elective major abdominal surgery due to gastrointestinal tumors were enrolled and divided into three groups according to analgesia methods; intravenous (IV) analgesia, abdominal wall block (B), and a combination of block plus intravenous analgesia (BIV). Diaphragm thickness and diaphragm thickening fractions were measured preoperatively and postoperatively using ultrasound during rest and forced inspiration. The primary parameter was the prevention of diaphragm dysfunction by BIV compared to other methods. The secondary outcome was the change in diaphragm thickening fractions at rest and during maximal inspiration compared to preoperative values.

Results: No patients demonstrated clinical diaphragm dysfunction based on contraction indices. However, postoperative diaphragm thickening fractions decreased significantly in the IV group at rest and in the B group during maximal inspiration ($p<0.05$), whereas no significant reduction was observed in the BIV group. BIV provided significantly better postoperative pain control (lower VAS scores) and was associated with preserved diaphragm thickening fractions, supporting a potential protective effect on diaphragmatic function.

Conclusion: Major abdominal surgery leads to a measurable decline in diaphragmatic contractility in patients receiving single-modality analgesia (B or IV), whereas combined BIV analgesia preserves postoperative diaphragm function while improving pain control. These findings suggest that multimodal analgesia may help protect respiratory muscle performance in the early postoperative period.

Keywords: Analgesia, diaphragm, postoperative pain

INTRODUCTION

In the postoperative period following major abdominal surgery, respiratory function often declines, largely due to surgery-induced pain, which impairs diaphragmatic activity. Diaphragmatic dysfunction may lead to inadequate ventilation, atelectasis, and secretion retention.[1] Ultrasound-based measurements of diaphragm thickness and thickening fractions provide an objective and reproducible method to evaluate postoperative diaphragmatic performance. However, few studies have directly compared the impact of different analgesia methods on these parameters.

The impact of analgesia methods on diaphragm function remains a subject of debate. In particular, there is a limited number of studies that objectively assess the effects of different analgesia techniques on diaphragm thickness and contractile capacity. Ultrasound-based measurements of diaphragm thickness and diaphragm thickening fractions provide a reliable and objective means of evaluating these functional changes.[2,3]

This study aims to evaluate the effects of different postoperative analgesia methods on diaphragm muscle thickness and functional indices. Preoperative measurements were conducted to confirm that patients initially had normal diaphragm function; however, the primary focus was placed on postoperative measurements. The main parameter assessed in the study was whether there was a postoperative reduction in the diaphragm thickening fractions measured during maximal inspiration. In addition, the study investigated whether reductions occurred in the diaphragm thickening fractions at rest breath and during maximal inspiration compared to preoperative values.

Within this context, changes in diaphragm parameters were compared among three different analgesia groups (intravenous analgesia only, abdominal plane block only, and a combination of plane block and intravenous analgesia) in order to determine which method exerts the least respiratory impact.

Corresponding Author: Fethi Gültop, fethigultop@yahoo.com

This study compared the effects of intravenous (IV) analgesia, abdominal plane block (B), and combined analgesia (BIV) on postoperative diaphragm function, with a focus on changes in diaphragm thickening fractions relative to baseline measurements.

METHODS

Study Design

This prospective observational clinical study was conducted over a five-month period following approval from the Prof. Dr. Cemil Taşcıoğlu City Hospital Clinical Researches Ethics Committee (Date: 09.10.2023, Decision No: 201). All procedures were carried out in accordance with the ethical rules and the principles of the Declaration of Helsinki. During this period, adult patients scheduled for elective major abdominal surgery due to gastrointestinal system tumors were evaluated. Inclusion criteria were: age ≥18 years, planned elective major abdominal surgery, and provision of informed consent. Exclusion criteria included a body-mass index (BMI) >35 kg/m², a history of neuromuscular disease, advanced-stage chronic respiratory disease, previous abdominal or thoracic surgery, inability to communicate (e.g., language barrier, mental retardation), or illiteracy.

All patients were informed about the study and gave written consent. To confirm normal preoperative diaphragm function and enable comparison with postoperative measurements, an ultrasonographic assessment was performed, and preoperative measurements were recorded.

Patient Grouping

Postoperative analgesia methods were observed and recorded for each patient. While most patients were treated with one of three primary analgesia techniques, a small number received epidural analgesia. However, since only five patients received epidural analgesia, this subgroup was excluded from the study due to the inability to perform statistically reliable analyses. Consequently, statistical evaluations were limited to patients within the three main analgesia groups. The sample size was determined based on a power analysis targeting the comparison of diaphragm thickening fractions at rest breath and maximal inspiration across the three analgesia groups (plane block, intravenous analgesia, and a combination of both). Using G*power 3.1 software, the analysis assumed an effect size of f=0.4 (moderate-to-large), a significance level (α) of 0.05, and a power of 0.80. Based on one-way ANOVA, it was estimated that a minimum of 66 patients would be required. Accordingly, cases undergoing elective surgery during the study period were prospectively recorded and grouped by the analgesia method administered. Once a group reached 22 patients, no additional patients were included in that group.

- **Group IV (n=22):** Intravenous analgesia only
- **Group B (n=22):** Abdominal plane block only
- **Group BIV (n=22):** Combination of abdominal plane block and intravenous analgesia

Analgesia Protocols

All patients underwent general anesthesia and laparotomy for the surgical procedure. Anesthesia induction was achieved with propofol (2.5 mg/kg) and rocuronium (0.6 mg/kg) as a muscle relaxant. Additionally, fentanyl (0.5 μg/kg) was administered to maintain hemodynamic stability. Maintenance of anesthesia was achieved with sevoflurane (MAC=2), and sugammadex (2 mg/kg) was administered prior to extubation to reverse the neuromuscular blockade and prevent any residual block at the conclusion of the procedure. Postoperative analgesia was provided using intravenous and/or abdominal plane block techniques. The analgesia protocols were as follows.

- Intravenous (IV) analgesia: In our routine practice, 1000 mg paracetamol and 100 mg tramadol are administered intravenously approximately 15 minutes before the end of surgery as a single-dose infusion. Bilateral ultrasound-guided transverse abdominis plane (TAP) block with 20 ml of 0.25% bupivacaine per side is performed at the end of surgery prior to extubation as a single administration. No repeat doses are given.
- Abdominal plane block: At the end of surgery, prior to extubation, a bilateral transverse abdominis plane (TAP) block is administered under ultrasound guidance, following strict aseptic techniques. For the TAP block, 20 ml of 0.25% bupivacaine is injected on each side between the transversus abdominis and internal oblique muscles. This block is performed as a single administration, without repetition.

In our routine practice, patients are evaluated for pain at the first postoperative hour. Additional intravenous analgesics are administered to those requiring supplemental pain control. However, diaphragm measurements were obtained prior to any assessment of additional analgesic needs, ensuring that our results were not influenced by postoperative analgesic interventions.

Diaphragm Assessment

There are two main acoustic windows to visualize the diaphragm:[3]

- The zone of apposition between the 8th and 10th intercostal spaces on the mid- or anterior axillary line, 0.5-2 cm below the costophrenic sinus, where a high-frequency linear probe (≥10 MHz) is essential.
- The subcostal region, between the midclavicular and anterior axillary lines, using the liver or spleen as an acoustic window; here, a cardiac or abdominal probe (2-5 MHz) can be used.

The first method was adopted in our study. Diaphragm thickness was evaluated in the supine position, at the xiphoid level (between the 8th and 10th intercostal spaces), just below the anterior axillary line using a high-frequency linear ultrasound probe.[2] A skin-safe marker was used to mark the probe's position on the patient's body to ensure consistent placement during follow-up measurements, as diaphragm thickness may vary depending on the measurement site. This practice helps maintain measurement reproducibility.[4]

In B-mode imaging (**Figure 1**) at a depth of 1.5-3 cm, two parallel echogenic lines were easily identified: the more superficial one corresponding to the parietal pleura and the deeper one to the peritoneum. The diaphragm appears as the less echogenic structure between these two lines.[3] Subsequently, M-mode (**Figure 2**) was used to record the measurements. The distance between the parietal pleura and peritoneum was measured along a perpendicular line during inspiration, expiration, and forced inspiration. Three parameters were measured during each assessment: diaphragm thickness during inspiration (mm), expiration (mm), and maximal inspiration (mm).

Diaphragm measurements were first obtained preoperatively as baseline values. Postoperative assessments were performed in the post-anesthesia care unit (PACU) one hour after extubation, once patients had adequate emergence from anesthesia and muscle strength. Diaphragm thickness was recorded at end-expiration and peak inspiration during quiet and maximal breathing for both time points, and values were documented for comparison.

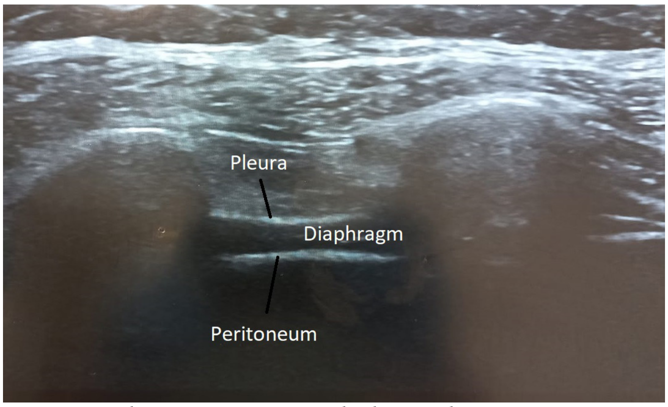

Figure 1. Diaphragmatic view in B-mode ultrasound

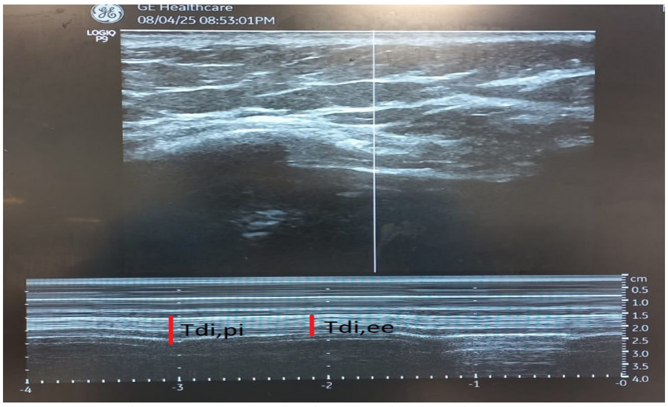

Figure 2. Diaphragmatic M-mode ultrasound image during quiet breathing

In addition, diaphragm thickening fractions were calculated using the following formulas:[2]

Thickening fraction in rest breath:

$$TF_{di}(\%) = \frac{(T_{di,pi} - T_{di,ee})}{T_{di.ee}} \ X \ 100$$

TFdi (%): diaphragm thickening fraction,
Tdi, pi: diaphragm thickness at peak inspiration,
Tdi, ee: diaphragm thickness at end expiration.

Thickening fraction in maximal inspiration:

$$TF_{di,max}(\%) = \frac{(T_{di,pi} - T_{di,ee})}{T_{di.ee}} \ X \ 100$$

TFdi, max (%): Maximal diaphragm thickening fraction,
Tdi, pi: diaphragm thickness at peak inspiration,
Tdi, ee: diaphragm thickness at end expiration.

Preoperative measurements were used as control values to confirm that patients had normal diaphragm function. The primary evaluation focused on postoperative measurements, particularly the potential reduction in the maximal diaphragm thickening fractions. Comparisons were also made with preoperative values. Previous studies have identified a diaphragm thickening fraction (TFdi) in the range of approximately 30% to 260% as normal.[2,5] A maximum TFdi value below 20% is considered diagnostic of severe diaphragm dysfunction.[2,6,7]

In this study, we measured the patients' diaphragmatic thickness at rest and during maximal inspiration in the preoperative and postoperative periods, calculated their diaphragm thickening fractions, and evaluated them for diaphragmatic dysfunction. We also investigated the relationship of the results with the analgesia method.

Statistical Analysis

Descriptive statistics for continuous variables were reported as mean±standard deviation, median, minimum, and maximum values. Categorical variables were presented as counts and percentages. The Shapiro-Wilk test was used to assess the normality of continuous variables.

For comparison of continuous variables across anesthesia groups, one-way ANOVA was used for normally distributed data, and the Kruskal-Wallis test for non-normally distributed data. The Kruskal-Wallis multiple comparison test was applied to identify which groups accounted for any significant differences.

The Wilcoxon test was used to compare preoperative and postoperative diaphragm thickening fractions. For nominal variables in contingency tables, the Chi-square test or Fisher's exact test was used as appropriate.

All statistical analyses were performed using IBM SPSS version 20 (Chicago, IL, USA), with a p-value of <0.05 considered statistically significant.

RESULTS

The demographic characteristics and operative data of the patients included in the study are presented in Table 1. A total of 66 patients were enrolled. The mean age was 67.11±10.52 years, with a minimum age of 40 and a maximum age of 87 years. The mean BMI was 25.45±5.11.

Table 1. Demographic characteristics and surgical parameters of the patients

Variable	Mean±SD	Median (min-max)
Type of surgery		
Low anterior resection (rectal CA)	20	30.3%
Gastric CA staging	1	1.5%
Total gastrectomy	9	13.6%
Subtotal gastrectomy	10	15.2%
Rectal resection+liver resection	**1**	**1.5%**
Colectomy	25	37.9%
Type of analgesia		
Block only (B)	22	33.3%
Intravenous only (IV)	22	33.3%
Combination (BIV)	22	33.3%

SD: Standard deviation, Min: Minimum, Max: Maximum, BMI: Body-mass index, PEEP: Positive end expirauar pressure, PPEAK: Peak airway pressure, VAS: Visual Analogue Scale, ASA: American Society of Anesthesiologists, CA: Cancer, B: Block, IV: Intravenous, BIV: Block intravenous

The average duration of surgery was 202.88±58.31 minutes. The mean tidal volume was 482.35±46.45 ml, the mean PEEP was 5.12±0.56 cmH_2O, and the mean peak airway pressure (PPEAK) was 18.26±3.26 cmH_2O.

The median postoperative VAS score was 4, and the median Aldrete score was 10. The mean length of hospital stay was 6.70±7.26 days.

Of the patients, 62.1% were male; 48.5% had an ASA score of 3; and 37.9% underwent colectomy.

Table 2 shows that the groups were demographically similar, with no statistically significant differences among them (p>0.05). However, a significant difference was observed in ASA scores (p<0.05), attributable to a higher proportion of ASA 3 patients in the BIV group.

Postoperative VAS scores differed significantly among the groups (p<0.001), with the BIV group demonstrating significantly lower scores than the other groups (p<0.001; Figure 3).

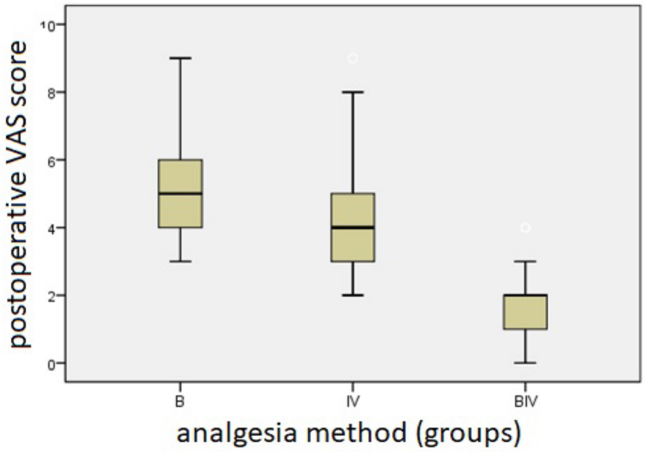

Figure 3. Postoperative VAS scores by analgesia group

VAS: Visual Analogue Scale

The length of hospital stay also differed significantly among the groups (p<0.01), being longer in the BIV group compared to both the B and IV groups.

Table 3 presents the diaphragm thickening fractions and maximal inspiration diaphragm thickening fractions measured in the preoperative and postoperative periods.

Table 3. Preoperative and postoperative comparison of diaphragm thickening fractions

Parameter		Mean±SD (n=66)	Median (min-max)
Preoperative	TFdi	34.09±23.55	30.78 (2.78-147.62)
	TFdi,max	104.61±52.12	101.78 (20.59-242.86)
Postoperative	TFdi	27.68±14.54	26.49 (5.26-69.23)
	TFdi,max	89.53±54.36	80.19 (19.05-276.47)

SD: Standard deviation, Min: Minimum, Max: Maximum, TFdi: Diaphragm thickening fractions, TFdi,max: Maximal diaphragm thickening fraction

In both preoperative and postoperative assessments, patients demonstrated normal diaphragm thickness and thickening fraction indices, and no diaphragmatic dysfunction was observed. However, postoperative measurements showed a decrease in diaphragm thickening fractions compared with baseline values.

Table 4 provides the statistical comparison of preoperative and postoperative diaphragm indices. Diaphragm thickening fractions were significantly lower in the postoperative period compared to preoperative values (p<0.01). Similarly, maximal diaphragm thickening fractions decreased significantly postoperatively (p<0.05).

Table 4. Comparison of pre- and postoperative diaphragm thickening fractions

	Preoperative (n=66)	Postoperative (n=66)	
Index	Mean±SD Median (min-max)	Mean±SD Median (min-max)	p-value
TFdi	34.09±23.55 30.78 (2.78-147.62)	27.68±14.58 26.49 (5.26-69.23)	0.007[d]
TFdi,max	104.61±52.12 101.78 (20.59-242.86)	89.53±54.36 80.19 (19.05-276.47)	0.038[d]

SD: Standard deviation, Min: Minimum, Max: Maximum, TFdi: Diaphragm thickening fractions, TFdi,max: Maximal diaphragm thickening fraction, d: Wilcoxon test

Table 5 compares the preoperative and postoperative diaphragm measurements across the analgesia groups. Patients receiving IV analgesia demonstrated a significant postoperative reduction in diaphragm thickening fraction (p<0.05), and the B group showed a significant decrease in maximal diaphragm thickening fraction (p<0.05). In contrast, no significant reduction was detected in either resting or maximal thickening fractions in the BIV group (p>0.05),

Table 2. Comparison of demographic characteristics among the groups

	B group (n=22)	IV group (n=22)	BIV group (n=22)	
Parameter	Mean±SD (median)	Mean±SD (median)	Mean±SD (median)	p-value
Age (years)	65.50±11.17 (69)	69.23±8.45 (71)	66.59±11.79 (66)	0.490[a]
BMI (kg/m^2)	23.95±4.41 (23)	25.55±3.84 (25)	26.86±6.51 (26)	0.414[b]
Postoperative VAS	5.36±1.81 (5)	4.50±2.11 (4)	1.82±1.00 (2)	<0.001[b]
Aldrete recovery score	9.64±0.58 (10)	8.68±0.78 (8)	9.64±0.72 (10)	<0.001[b]
Hospital stay (days)	4.64±1.78 (4)	7.95±12.09 (5)	7.50±2.72 (7)	0.001[b]
	n (%)	n (%)	n (%)	
Female (%)	8 (36.4)	10 (45.5)	7 (31.8)	0.634[c]
Male (%)	14 (63.6)	12 (54.5)	15 (68.2)	
ASA 1 (%)	7 (31.8)	3 (13.6)	0	0.017[c]
ASA 2 (%)	6 (27.3)	11 (50.0)	7 (31.8)	
ASA 3 (%)	9 (40.9)	8 (36.4)	15 (68.2)	

[a]: One-way ANOVA, [b]: Kruskal-Wallis test, [c]: Chi-square test / Fisher's exact test, B: Block, IV: Intravenous, BIV: Block intravenous, SD: Standard deviation, BMI: Body-mass index, VAS: Visual Analogue Scale, ASA: American Society of Anesthesiologists

indicating relative preservation of diaphragmatic function (**Figure 4, 5**).

Tablo 5. Comparison of preoperative and postoperative diaphragm thickening fractions in groups

		Preop	Postop	
	Group	Mean±SD Median (min-max)	Mean±SD Median (min-max)	p-value
Diaphragm thickening fractions	B	41.30±34.51 32.45 (2.78-147.62)	31.59±17.86 25.65 (8.57-69.23)	0.093[d]
	IV	31.91±17.11 32.45 (10.64-76.92)	24.07±11.77 25.65 (5.26-44.0)	0.024[d]
	BIV	29.07±12.10 28.0 (11.76-55.56)	27.40±12.94 27.27 (6.06-63.64)	0.538[a]
Maximal diaphragm thickening fractions	B	133.26±59.36 127.27 (25.0-242.86)	113.75±62.80 95.0 (43.75-276.47)	0.046[d]
	IV	98.01±40.88 89.56 (34.62-176.82)	73.55±41.99 63.33 (19.05-168.0)	0.115[d]
	BIV	82.57±42.39 78.63 (20.59-215.38)	81.30±49.87 77.27 (20.0-245.45)	0.833[d]

SD: Standard deviation, Min: Minimum, Max: Maximum, B: Block, IV: Intravenous, BIV: Block intravenous, d: Wilcoxon test

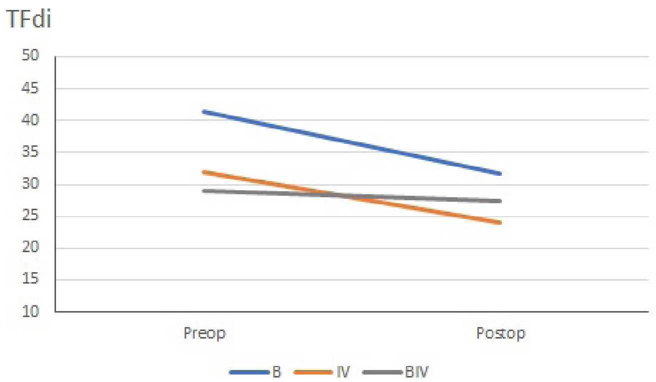

Figure 4. Changes in diaphragm thickening fraction from preoperative to postoperative periods

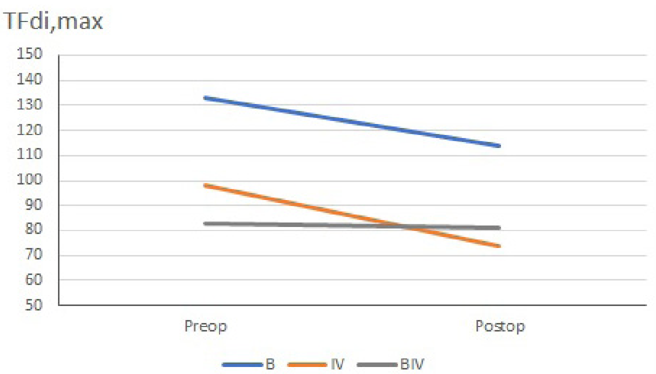

Figure 5. Changes in maximal diaphragm thickening fraction from preoperative to postoperative periods

DISCUSSION

This study demonstrates that major abdominal laparotomy is associated with a measurable decline in diaphragmatic contractility, which is attenuated by combined (BIV) analgesia. These findings are clinically relevant because postoperative diaphragmatic dysfunction predisposes patients to respiratory complications, and our results indicate that analgesic technique influences the extent of this impairment.

Diaphragmatic thickness and thickening fractions measured by ultrasound are affected by individual factors such as age, body mass index, and gender.[8] Although no significant demographic differences were found between the groups in this study, we evaluated diaphragm thickening fractions, which are more standardized and have clearly defined threshold values in the literature, to minimize variability.

The BIV group had a longer hospital stay than the other groups, which we attributed to the higher prevalence of comorbidities, as reflected by the greater proportion of ASA 3 patients.

Conversely, postoperative VAS scores were significantly lower in the BIV group (**Table 2**), as expected. The combination of a regional block (targeting somatic pain) and intravenous analgesia (addressing visceral pain) provides more comprehensive analgesia, resulting in superior pain control.

We hypothesized that groups with lower postoperative pain would demonstrate better preservation of diaphragmatic function. Our analysis partially confirmed this: the IV group exhibited a significant reduction in resting diaphragm thickening fraction, and the B group showed a significant reduction in maximal diaphragm thickening fraction, whereas the BIV group demonstrated no significant postoperative decline in either parameter.

This relative preservation of diaphragmatic function in the BIV group highlights the potential functional benefit of multimodal analgesia.

The absence of neuromuscular monitoring with train-of-four (TOF) is a limitation of this study. Although neuromuscular monitoring with TOF could have provided additional objective confirmation, postoperative measurements were obtained one hour after extubation, and sugammadex (2 mg/kg) was administered to reverse rocuronium-induced blockade. Moreover, TOF is not routinely used in postoperative recovery in clinical practice;[9,10] instead, objective criteria such as the Aldrete score are preferred. In our study, a median Aldrete score of 10 supported the assumption of adequate recovery of muscle strength during measurements.

Our findings are consistent with previous studies reporting that abdominal surgery leads to early postoperative diaphragmatic dysfunction,[1] and they suggest that multimodal analgesia can attenuate this decline by providing superior pain control.

It is well known that postoperative pain restricts respiratory mechanics.[11] In our study, the BIV group had significantly lower VAS scores, confirming that combined analgesic approaches offer more effective pain control. Unlike the IV and B groups, this improved pain control was associated with preserved diaphragmatic thickening fractions, highlighting the potential functional benefit of multimodal analgesia. Previous studies have similarly shown that upper abdominal surgery can lead to marked diaphragmatic dysfunction lasting up to a week, which cannot be entirely prevented by analgesia.[1] Our results suggest that sufficient multimodal analgesia may not only reduce VAS scores but also support diaphragmatic contractility in the immediate postoperative period.

Although epidural analgesia has been shown to improve postoperative respiration and reduce pulmonary complications,[12] no patients in our study groups received epidural analgesia. The observed protective effect of combined BIV analgesia may be considered functionally analogous to the benefits described with epidural techniques in previous studies.

A key strength of this study is the quantitative, non-invasive, and reproducible assessment of diaphragmatic function using ultrasonography. While many studies have assessed diaphragm dysfunction, relatively few have compared the effects of different analgesia methods on diaphragm thickening fractions.[12-14]

Limitations

Nevertheless, the study has certain limitations. Most notably, we could not control for other potential factors affecting diaphragm function (e.g., postoperative fatigue, residual anesthetic effects, subjective nature of pain, or subgroup variations in surgical type). Moreover, the absence of neuromuscular monitoring techniques such as TOF limits the objectivity of diaphragmatic function assessment. Even though the ultrasound measurements were performed by an experienced practitioner, operator dependency remains a potential source of bias affecting measurement reliability.

CONCLUSION

Our findings indicate that major abdominal laparotomy leads to a measurable decline in diaphragmatic function in patients receiving single-modality analgesia (IV or B), as demonstrated by postoperative reductions in diaphragm thickening fractions. In contrast, combined BIV analgesia preserved diaphragmatic function and was associated with lower postoperative VAS scores, suggesting a protective effect on respiratory muscle performance. These results support the integration of multimodal analgesia into perioperative management as a comprehensive strategy to maintain early postoperative respiratory function in patients undergoing major abdominal surgery.

ETHICAL DECLARATIONS

Ethics Committee Approval

The study was carried out with the permission of the Prof. Dr. Cemil Taşcıoğlu City Hospital Clinical Researches Ethics Committee (Date: 09.10.2023, Decision No: 201).

Informed Consent

All patients signed and free and informed consent form.

Referee Evaluation Process

Externally peer-reviewed.

Conflict of Interest Statement

The authors have no conflicts of interest to declare.

Financial Disclosure

The authors declared that this study has received no financial support.

Author Contributions

All of the authors declare that they have all participated in the design, execution, and analysis of the paper, and that they have approved the final version.

Acknowledgments

The authors gratefully acknowledge the volunteers.

REFERENCES

1. Simonneau G, Vivien A, Sartene R, et al. Diaphragm dysfunction induced by upper abdominal surgery. Role of postoperative pain. *Am Rev Respir Dis.* 1983;128(5):899-903. doi:10.1097/00132586-198512000-00026
2. Bellissimo CA, Morris IS, Wong J, Goligher EC. Measuring diaphragm thickness and function using point-of-care ultrasound. *J Vis Exp.* 2023;2023(201):1-12. doi:10.3791/65431
3. Zambon M, Greco M, Bocchino S, Cabrini L, Beccaria PF, Zangrillo A. Assessment of diaphragmatic dysfunction in the critically ill patient with ultrasound: a systematic review. *Intensive Care Med.* 2017;43(1):29-38. doi:10.1007/s00134-016-4524-z
4. Goligher EC, Laghi F, Detsky ME, et al. Measuring diaphragm thickness with ultrasound in mechanically ventilated patients: feasibility, reproducibility and validity. *Intensive Care Med.* 2015;41(4):642-649. doi:10.1007/s00134-015-3687-3
5. Boussuges A, Rives S, Finance J, et al. Ultrasound assessment of diaphragm thickness and thickening: reference values and limits of normality when in a seated position. *Front Med.* 2021;8:1-8. doi:10.3389/fmed.2021.742703
6. Gottesman E, McCool FD. Ultrasound evaluation of the paralyzed diaphragm. *Am J Respir Crit Care Med.* 1997;155(5):1570-1574. doi:10.1164/ajrccm.155.5.9154859
7. Boon AJ, Harper CJ, Ghahfarokhi LS, Strommen JA, Watson JC, Sorenson EJ. Two-dimensional ultrasound imaging of the diaphragm: quantitative values in normal subjects. *Muscle Nerve.* 2013;47(6):884-889. doi:10.1002/mus.23702
8. van Doorn JLM, Wijntjes J, Saris CGJ, Ottenheijm CAC, van Alfen N, Doorduin J. Association of diaphragm thickness and echogenicity with age, sex, and body-mass index in healthy subjects. *Muscle Nerve.* 2022;66(2):197-202. doi:10.1002/mus.27639
9. Deshmukh PP, Chakole V. Post-anesthesia recovery: a comprehensive review of sampe, modified aldrete, and white scoring systems. *Cureus.* 2024;16(10):e70935. doi:10.7759/cureus.70935
10. Ding D, Ishag S. Aldrete Scoring System.; 2023. https://www.ncbi.nlm.nih.gov/books/NBK594237/
11. Canet J, Mazo V. Postoperative pulmonary complications. *Minerva Anestesiol.* 2010;76(2):138-181.
12. Beaussier M, Genty T, Lescot T, Aissou M. Influence of pain on postoperative ventilatory disturbances. Management and expected benefits. *Ann Fr Anesth Reanim.* 2014;33(7-8):484-486. doi:10.1016/j.annfar.2014.07.005
13. Dot I, Pérez-Teran P, Samper MA, Masclans JR. Diaphragm dysfunction in mechanically ventilated patients. *Arch Bronconeumol.* 2017;53(3):150-156. doi:10.1016/j.arbr.2016.12.011
14. Umbrello M, Formenti P, Longhi D, et al. Diaphragm ultrasound as indicator of respiratory effort in critically ill patients undergoing assisted mechanical ventilation: a pilot clinical study. *Crit Care.* 2015;19(1):1-10. doi:10.1186/s13054-015-0894-9