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Association between transversus abdominis plane block and cortical responses to intraoperative noxious stimuli during laparoscopic sleeve gastrectomy: a retrospective observational EEG study

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Research Article

Keywords: Peripheral nerve blocks, Bariatric surgery, Postoperative pain, Psychological recovery, Obesity

Posted Date: November 19th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-11470656/v1

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Additional Declarations: No competing interests reported.

Abstract

Objective

Conventional intraoperative monitoring during laparoscopic sleeve gastrectomy (LSG) poorly distinguishes specific noxious stimuli, limiting targeted analgesia. Intraoperative electroencephalography (EEG) provides a potential objective measure to detect cortical responses to surgical events and evaluate the effects of transversus abdominis plane (TAP) block.

Methods

We included 64 patients from an ambispective cohort who underwent laparoscopic sleeve gastrectomy (LSG) and were divided into a general anesthesia (GA) group and a transversus abdominis plane block (TAPB) group. Perioperative clinical and hemodynamic data were collected. Electroencephalographic (EEG) power spectral density (PSD) and nonlinear/spectral entropy features were extracted. Generalized linear models (GLMs) adjusted for age, sex, body mass index (BMI), and American Society of Anesthesiologists (ASA) physical status assessed group differences at each time point, with false discovery rate (FDR) correction for multiple comparisons.

Results

Demographics, anesthetic doses, and adverse event rates were similar between groups. At T1 (skin incision) and T2 (pneumoperitoneum), TAP patients exhibited pronounced suppression of alpha and beta PSD compared with GA patients (FDR-corrected $P < 0.05$). Global EEG power and activity were consistently lower in the TAP group. Heart rate variability was reduced with TAP (14.7 ± 5.3 vs. 17.3 ± 4.5; $P = 0.040$). Obese patients in the GA group required more postoperative rescue analgesia before discharge (log-rank $P = 0.042$).

Conclusions

Multidimensional EEG revealed that TAP block significantly modulates cortical responses to incision and pneumoperitoneum but has limited influence on visceral stimulation. EEG-based measures may serve as objective indicators of intraoperative analgesia and support optimizing multimodal pain management during LSG.

Trial Registration:

Chinese Clinical Trial Registry, ChiCTR2400092228. Registered on 2024-05-12. Retrospectively registered.

1 Introduction

The rising prevalence of morbid obesity has made laparoscopic sleeve gastrectomy (LSG) the most frequently performed bariatric surgery since 2014.[1, 2] LSG involves several types of intraoperative noxious stimuli, including somatic stimulation (skin incision or trocar insertion), mechanical stimuli from peritoneal stretch and distension (pneumoperitoneum), and visceral stimulation (gastric resection).[3] These stimuli under general anesthesia (GA) can trigger cortical electroencephalography (EEG) changes, sympathetic activation, and hemodynamic instability, which are associated with worsened postoperative pain, increased opioid requirements, and delayed recovery,[4, 5] which is a challenge particularly to patients with morbid obesity[6]. Therefore, intraoperative management of noxious stimuli is critical during LSG.

In addition to detecting the under- and over-sedation during GA even when hemodynamic variables remain unchanged,[7] the EEG changes responded to noxious stimuli can be used to determine the pain management efficacy and further guide analgesia optimization.[8] EEG monitoring can immediately capture cortical responses to nociception, showing changes in spectral power and suppression or alpha suppression nearly as soon as the stimulus is applied.[9, 10] Changes in some of the EEG bands' power may precede or at least coincide with behavioral indications of nociception,[11] implying that EEG could provide earlier or more sensitive detection of nociceptive input than hemodynamic variables. Whether EEG can clearly detect cortical responses to different intraoperative noxious stimuli during surgery remains unclear.

Peripheral nerve blocks (PNBs) can significantly reduce analgesic consumption, enhance intraoperative hemodynamic stability, and attenuate postoperative pain in LSG.[12, 13] However, evidence linking PNBs–EEG responses–clinical outcomes remains scarce. Whether PNBs modulate nociception-related cerebral response translates into more stable hemodynamics and improved postoperative recovery is still unknown. In this study, we analyzed frontal EEG activity to key intraoperative stimuli (skin incision, pneumoperitoneum, and gastric resection) in obese patients undergoing LSG, comparing those with and without transversus abdominis plane block (TAPB). The primary objective of this retrospective study was to determine whether TAPB was associated with differential cortical EEG responses to predefined intraoperative noxious stimuli during LSG. Secondary analyses explored whether these EEG changes were accompanied by differences in perioperative hemodynamic stability and postoperative analgesic outcomes.

2 Material and methods

2.1 Study Population and Design

This retrospective observational study used perioperative clinical records and intraoperative EEG data from consecutive patients who underwent laparoscopic sleeve gastrectomy at the Second Affiliated Hospital of Anhui Medical University between May 8th 2021 and February 15th 2022. The study was

approved by the Ethics Committee of the Second Affiliated Hospital of Anhui Medical University (approval no. YX2023-088) on June 9th 2023 and was conducted in accordance with the Declaration of Helsinki. The study was registered in the Chinese Clinical Trial Registry (ChiCTR2400092228) on November 12th 2024. The first eligible patient included in this analysis underwent surgery on May 8th 2021. The requirement for individual informed consent was waived by the ethics committee due to the retrospective observational nature of this study. During the study period, 75 consecutive patients who underwent laparoscopic sleeve gastrectomy were identified. Eleven patients were excluded because their EEG recordings were uninterpretable or incomplete. The final cohort comprised 64 patients. Patients were classified according to anesthetic management recorded in the medical records: general anesthesia with transversus abdominis plane block (TAPB group, n = 31) or general anesthesia alone (GA group, n = 33). The decision to perform TAPB was made by the attending anesthesiologist according to routine clinical practice rather than the study protocol. The present retrospective analysis was designed to compare cortical EEG responses to predefined intraoperative noxious stimuli between the two groups.

2.2 Interventions and Magnetic Resonance Imaging (MRI)

At our institution, postoperative MRI assessment of injectate distribution was incorporated into a prospective imaging protocol evaluating the anatomical spread of TAPB during the study period. The present retrospective analysis used these routinely acquired imaging data. A standardized GA regimen was used in both groups (Supplementary Table S1). Before induction, patients in the TAP group received ultrasound-guided bilateral TAPB with a subcostal approach. Each block was achieved by single-injecting 30 mL of 0.33% ropivacaine containing dexmedetomidine 1 μg kg-1.[12]

A 3-T MRI observation (MAGNETOM Vida; Siemens Healthcare Tokyo, Japan) was performed at 1.5 hours after the injection to show the spread of local anesthetics. Coronal T2WI haste (2D) sequences were firstly performed as follows: repetition time/echo time (TR/TE) = 1400/88, field of view (FOV) = 480 mm, slice thickness = 8 mm, slice gap = 20%, scan time = 15 sec, bandwidth = 651, matrix = 384/307. Then, TRA T2-weighted sequences with fat suppression were performed as follows: TR/TE = 1600/96, FOV = 480 mm, slice thickness = 5 mm, slice gap = 20%, scan time = 17 sec, bandwidth = 651, matrix = 352/285. Lastly, coronal T2WI-SPACE sequences were used to reconstruct 3D as TR/TE = 2400/252, FOV = 480 mm, FOV phase = 100%, slice thickness = 1 mm, slice gap = 0, scan time = 5min 17s, bandwidth = 354, matrix = 224/220.[14]

2.3 EEG Acquisition

Frontal EEG is recorded continuously with a SedLine (Masimo Corp., CA, USA) during LSG. Sixty-second EEG epochs are extracted at three predefined phases: somatic-dominant stimulation (skin incision and trocar insertion, T1), visceral distension (pneumoperitoneum, T2), and visceral manipulation (gastric resection, T3). All operations were performed by the same surgical team. The study workflow is shown in Fig. 1.

2.4 EEG Signal Processing and Feature Extraction

EEG signals are band-pass filtered from 0.5 to 90 Hz in MATLAB R2022a and downsampled to 89 Hz. Normalized power spectral density (PSD) is computed using Welch's method and partitioned into δ (1–3 Hz), θ (4–7 Hz), α (8–12 Hz), β (13–30 Hz), and γ (31–90 Hz) bands.[15] Within each band, two types of features are derived: entropic nonlinear characteristics, including approximate entropy (ApEn), C0-complexity (C0), and permutation entropy (PerEn); spectral characteristics, including activity, total power, and complexity.[16] The EEG processing steps were shown in Fig. 1. Detailed calculation formulas for these features are provided in the Supplementary Methods. A 10-fold cross-validation approach was employed to evaluate classification performance. Three classifiers were utilized: K-Nearest Neighbors (KNN; Euclidean distance, N = 3 neighbors), random forest (RF; maximum number of features for splitting set to 57), and Support Vector Machine (SVM; quadratic kernel function). The experiment was repeated 10 times for robustness. Classifier performance was quantified using the following metrics: accuracy, recall, precision, F1-score, and specificity.[16]

2.5 Statistical analysis

Power analysis was conducted using the FDR-significant indicator with the smallest between-group effect size (F2 alpha at skin incision). With 33 participants in the GA group and 31 in the TAP group, and a two-sided α of 0.05, the simulated power of the Mann-Whitney U test was 80%, meeting the conventional threshold for statistical adequacy. Descriptive data were presented as mean ± standard deviation (SD), median (interquartile range, IQR), or percentages as appropriate. The assumption of data normality was confirmed through a Shapiro-Wilk test. Two independent sample *t*-test, Mann-Whitney U tests, or Chi-square tests were used to compare the baseline and perioperative characteristics between the two groups. The outcomes, including the PSD and EEG characteristics under different stimuli, were evaluated by two independent sample t-test or Mann-Whitney U tests with false discovery rate (FDR) correction for multiple comparisons within each time point. Generalized linear regression models (GLMs), adjusted with age, sex, BMI, and American Society of Anesthesiologists (ASA) physical status classification, were used to evaluate the association between group and each EEG feature. P values for GLMs were adjusted for multiple comparisons within each time point using the FDR method. The analyses were conducted in R software (version 4.4.1; R Foundation for Statistical Computing, Vienna, Austria). A two-sided *P* value less than 0.05 was considered as statistically significant.

3 Results

3.1 Patient Characteristics and Intervention

64 patients were included in the final analysis (GA group, n = 33; TAPB group, n = 31). Basic characteristics, including demographics and comorbidities, were comparable between groups. The mean age was 31.8 ± 6.6 vs 31.1 ± 4.1 years old; the proportion of female patients was 69.7% vs 80.6%; body weight was 108.0 [98.25–119.5] vs 110.0 [101.0-117.0] kg; and BMI was 39.16 [38.11–43.80] vs 41.51 [38.11–43.50] kg m^{-2} (all $P > 0.05$). The distribution of ASA physical status was similar (overall $P = 0.084$) (Table 1).

Table 1
Patients Characteristics

Characteristic	GA (n = 33)	TAP (n = 31)	*P* value
Age (years), mean (SD)	31.8 ± 6.6	31.1 ± 4.1	0.613
Sex, female, n (%)	23 (69.7)	25 (80.6)	0.312
Body weight (kg), median (IQR)	108.00 (98.25, 119.50)	110.00 (101.00, 117.00)	0.989
BMI (kg m^{-2}), median (IQR)	39.16 (38.11, 43.80)	41.51 (38.11, 43.50)	0.672
Smoking, n (%)	8 (24.2)	5 (16.1)	0.420
Drinking, n (%)	10 (30.3)	5 (16.1)	0.181
Fasting blood glucose (Mmol/l), median (IQR)	5.42 (4.85, 6.11)	5.79 (5.06, 8.84)	0.134
HbA1c (mmol/mol), median (IQR)	5.80 (5.50, 6.65)	6.10 (5.60, 8.40)	0.112
Diabetes mellitus, n (%)	4 (12.1)	9 (29.0)	0.093
Hypertension, n (%)	3 (9.1)	2 (6.5)	> 0.999
Hyperuricemia, n (%)	11 (33.3)	6 (19.4)	0.206
Hyperlipidemia, n (%)	10 (30.3)	7 (22.6)	0.485
OSA, n (%)	0 (0.0)	2 (6.5)	0.231
Fatty liver, n (%)	20 (60.6)	14 (45.2)	0.216
ASA physical status, n (%)			0.084
	4 (12.1)	7 (22.6)	
	28 (84.8)	19 (61.3)	
	1 (3.0)	5 (16.1)	

Data are represented as mean ± standard deviation (SD), median (interquartile range, IQR), or number (%). Abbreviations: BMI, body mass index; HbA1c, glycated haemoglobin; OSA, obstructive sleep apnea; ASA, American Society of Anesthesiologists. *P* values were from the Chi-square test, independent-samples *t* test, and Mann-Whitney U test.

MRI successfully described the spread areas of the injectate in TAP blocks by using 3D imaging (Supplementary Video). The injectate is consistently observed within the transversus abdominis plane, and spreads from the lateral border of the rectus sheath (linea semilunaris) medially to the xiphoid process. The spread pattern directly corresponds to the course of the T10-L2 (Fig. 2, Supplementary Video).

3.2 Perioperative Clinical Parameters

Anesthetic drugs, including sevoflurane, propofol, remifentanil, cisatracurium and dexmedetomidine, as well as durations of surgery and anesthesia, were also comparable in patients with obesity, either with or without TAPB (all P > 0.05; Supplementary Table S2). Although the coefficient of variation (CV) of heart rate (HR) during surgery and at admission to the anesthesia intensive care unit (AICU) was lower in patients in the TAP group than that in the GA group (14.71 ± 5.29 vs 17.30 ± 4.54; P = 0.040), CVs for systolic blood pressure (SBP), diastolic blood pressure (DBP), and mean arterial pressure (MAP) were comparable between the two groups (Supplementary Table S2, Supplementary Figure S1). Patients in the GA group and TAP group had similar visual analogue scale (VAS) scores at AICU admission (2 [1–2] vs 2 [1–3], P = 0.971), and rescue analgesia requirements (27.3% vs 12.9%, P = 0.264; Supplementary Table S2). However, patients with obesity in the GA group elicited a higher cumulative incidence of postoperative rescue analgesia before discharge (log-rank P = 0.042; Supplementary Figure S2). Incidence of postoperative nausea and vomiting (PONV) and length of hospital stay were not affected by TAPB (Supplementary Table S2).

3.3 EEG power-spectral and entropy features across surgical phases

At T1 (skin incision) and T2 (pneumoperitoneum) during surgery, distinct band-specific suppression of EEG power spectral density (PSD) was consistently observed in patients in the TAPB group rather than the GA group. After adjusting for age, sex, BMI, and ASA status, generalized linear regression models revealed frequency-band–specific reductions in the TAP group. Alpha power was significantly lower at four electrode sites (Fp1, Fp2, F7, and F8) at both T1 and T2. Theta power was significantly lower at Fp2, F7, and F8 at T1, whereas beta power was significantly reduced at F7 and F8 across both time points (*FDR*-corrected $P < 0.05$) (Fig. 2 and Supplementary Table S3). For spectral characteristics, after adjusting for covariates, showed significantly lower EEG activity (signal variance) and sumpower (total spectral power) across multiple electrode sites and power than those in the GA group at T1 and T2 (*FDR*-corrected $P < 0.05$) in the TAPB group. No significant differences are detected between the GA and TAPB groups in band-specific PSD or entropy metrics at T3 (gastric resection). Moreover, nonlinear entropic metrics showed no significant changes, suggesting that the TAP block did not markedly affect the irregularity or complexity of EEG signals (Table 2 and Supplementary Table S4).

Table 2
Significant generalized linear regression analyses of nonlinear entropic and spectral EEG characteristics

	β (95%CI)	P	FDR-P
Skin incision			
Spectral characteristics			
Fp1-alpha-Activity	-0.31 (-0.54, -0.08)	0.010	0.047
Fp1-alpha-Sumpower	-0.56 (-0.97, -0.16)	0.009	0.047
Fp1-beta-Activity	-0.34 (-0.57, -0.11)	0.005	0.045
Fp1-beta-Sumpower	-0.64 (-1.09, -0.19)	0.007	0.047
Fp2-beta-Complexity	0.06 (0.02, 0.10)	0.008	0.047
Fp2-beta-Activity	-0.33 (-0.58, -0.09)	0.011	0.047
F7-beta-Activity	-0.34 (-0.55, -0.12)	0.004	0.045
F7-beta-Sumpower	-0.65 (-1.07, -0.22)	0.005	0.045
F8-beta-Activity	-0.35 (-0.57, -0.13)	0.003	0.045
F8-beta-Sumpower	-0.69 (-1.12, -0.26)	0.003	0.045
Entropic nonlinear characteristics			
F7-beta-C0	0.06 (0.02, 0.11)	0.009	0.047
Pneumoperitoneum			
Spectral characteristics			
Fp1-alpha-Activity	-0.30 (-0.53, -0.08)	0.011	0.041
Fp1-alpha-Sumpower	-0.59 (-1.02, -0.17)	0.009	0.038
Fp2-alpha-Activity	-0.35 (-0.57, -0.12)	0.005	0.038
Fp2-alpha-Sumpower	-0.67 (-1.10, -0.24)	0.004	0.038
F7-alpha-Activity	-0.30 (-0.52, -0.08)	0.011	0.041
F7-alpha-Sumpower	-0.59 (-1.00, -0.18)	0.006	0.038
F8-alpha-Activity	-0.31 (-0.53, -0.09)	0.008	0.038
F8-alpha-Sumpower	-0.62 (-1.03, -0.22)	0.004	0.038
Fp1-beta-Activity	-0.33 (-0.59, -0.07)	0.014	0.045

ApEn, Approximate Entropy; C0, C0-complexity.

	β (95%CI)	P	FDR-P
Skin incision			
Spectral characteristics			
Fp2-beta-Activity	-0.38 (-0.65, -0.11)	0.008	0.038
F7-beta-Activity	-0.34 (-0.58, -0.10)	0.008	0.038
F7-beta-Sumpower	-0.67 (-1.17, -0.16)	0.012	0.042
F8-beta-Activity	-0.36 (-0.59, -0.13)	0.004	0.038
F8-beta-Sumpower	-0.72 (-1.21, -0.22)	0.006	0.038
Entropic nonlinear characteristics			
Fp2-beta-ApEn	0.03 (0.01, 0.06)	0.008	0.038
β coefficients with 95% confidence intervals obtained from generalized linear regression models adjusted for age, sex, BMI, and ASA status. FDR-P value were corrected for multiple comparisons at each time point using the false discovery rate method.			
ApEn, Approximate Entropy; C0, C0-complexity.			

3.4 Classification performance based on EEG features

As shown in Fig. 4 and Supplementary Table S5, at T1 with α band features, the KNN classifier yields 63.3% accuracy, 66.8% precision, 58.3% recall, 68.3% specificity, and a 59.5% F1-score. Random forest and SVM show similar performance (accuracy 67.3% and 66.0%, other metrics 54.2–70.8%). With β band features, KNN attains 65.0% accuracy, 70.0% precision, and a 66.6% F1-score, with comparable results for other models. At T2 and T3, all classifiers show accuracy of 48.7% with F1-scores below 60%, not exceeding chance performance ($P > 0.05$).

4 Discussion

This study systematically evaluated the effect of adjunct TAPB to GA on intraoperative EEG responses during LSG, compared to GA alone. TAPB was associated with the suppression of α, θ, and β power at electrodes during skin incision and pneumoperitoneum, even after adjustment for covariates, suggesting greater stability of cortical activity. In addition, the TAPB significantly reduced spectral characteristics on incision and pneumoperitoneum, rather than gastric resection, indicating its efficacy on mechanical nociception. Furthermore, they showed lower HR variability (CV for HR, $P = 0.040$) and lower cumulative incidence of rescue analgesics (log-rank $P = 0.042$). The machine learning classifiers achieved only moderate discrimination, suggesting that intraoperative EEG analysis might provide supplementary information for anesthesia and pain management.

Emerging evidence suggests that EEG monitoring, especially signals and arrays of cortical features, provides advantages over conventional indices as one of the new predictors for monitoring pain.[17] Traditional methods, such as hemodynamic and nociceptive index, are limited by inter-individual variability and insufficient sensitivity, preventing timely and accurate discrimination of these cortical differences and resulting in an “analgesic blind spot”.[18–20] The EEG wave oscillations in multiple frequency bands differentially encode noxious stimulus intensity and pain intensity in chronic pain syndromes.[21, 22] In this study, we found that distinct cortical EEG responses were also elicited by different types of nociceptive stimuli during LSG. In particular, during skin incision and pneumoperitoneum, patients in the GA group showed larger increases in θ, α, and β, and greater spectral activity than those in the TAPB group, although a bidirectional EEG pattern for α frequency during pain.[23] These differences indicated that the TAP block mitigated the analgesic deficit associated with both skin incision and peritoneal stretch induced by pneumoperitoneum. However, comparable EEG responses between the two groups were observed during gastric resection, suggesting limited modulation of deeper visceral nociception by the TAP block. Our findings extend evidence that intraoperative EEG can capture differential cortical responses to nociceptive stimuli, thereby reinforcing its potential clinical utility, which was consistent with prior studies.[9, 24, 25]

These group differences may be explained by neuroanatomical mechanisms. Somatic pain from skin incision is primarily transmitted through sensory fibers of the spinal nerves (Aδ and C fibers) that enter the spinal cord and ascend via the spinothalamic and spinoreticular tracts to brain centers.[26, 27] During pneumoperitoneum, peritoneal stretch and distension produce mechanical stimulation, possibly shared spinal afferents.[28] Evidence from MRI further supports that local anesthetic blockade, such as TAPB, can readily cover these afferent fibers, thereby suppressing nociceptive transmission and pain perception associated with somatic stimulation.[14, 29, 30] While for visceral pain, besides spinal nerves, the autonomic nervous system, including sympathetic and vagal fibers, was also involved.[27] Some of these afferent pathways are located deeper and are more diffusely distributed, making them less accessible for local blockade.[31] This may explain the limited efficacy of TAPB in modulating visceral nociception,[32] which is often accompanied by autonomic manifestations such as nausea, sweating, and hemodynamic fluctuations.[33] These complexities of neuroanatomical and physiological mechanisms could be responsible for the limited analgesic effect of TAPB on visceral nociception, underscoring the importance of optimizing perioperative pain control.

Our previous randomized controlled trial suggested that, compared with GA, patients with morbid obesity who received TAPB showed lower postoperative pain scores in both somatic and visceral pain and better recovery performance.[12] Dai and colleagues also found the analgesic effect of TAPB on visceral pain among patients who underwent laparoscopic cholecystectomy.[34] Our inconsistent efficacy of TAPB on visceral pain may be related to the assessment time, with the previous trial assessing postoperative pain scores and the current analysis capturing immediate intraoperative responses. Anatomically, the TAPB can block thoracolumbar nerves from T6 to L1, which innervate the abdominal wall and the parietal peritoneum, and effectively relieve incisional pain and parietal peritoneal pain. Another clinical study showed that the TAPB could persist for more than 8 hours,[35] and provide pain control in the early

postoperative period, in which visceral discomfort occurs. Furthermore, postoperative pain scores were also influenced by multiple factors, such as remedial analgesics, inflammatory responses, psychological status, adverse events, and overall recovery, beyond the TAPB.[36, 37] We also observed reduced coefficient of variation of intraoperative HR and fewer rescue analgesic requirements in the TAP group, which may reflect the partial protective effect of TAPB on visceral nociception. By contrast, intraoperative EEG directly captures cortical responses to nociceptive input in real time and is less affected by these factors.[25, 38] Taken together, these findings suggest that the efficacy of TAPB may be characterized by intraoperative neurophysiological data and postoperative outcomes.

In this study, we utilized multi-channel SedLine EEG monitoring and integrated several parameters, including power spectrum and entropy, to conduct a comprehensive and quantitative analysis of EEG signals, offering a novel approach for intraoperative analgesia monitoring. There were several limitations in this analysis. First, dermatomal sensory assessment was not routinely documented because this retrospective analysis was based on perioperative records. Consequently, TAPB success could not be confirmed using sensory attenuation, which remains the clinical reference standard. Second, although the sample size, while satisfying the established statistical efficacy criteria, remains relatively small, necessitating validation in a larger study. Third, EEG data were exclusively obtained during intraoperative anesthesia, lacking a corresponding analysis with postoperative subjective pain scores and rehabilitation indices. Fourth, this study focused solely on the prefrontal four-lead signals, neglecting alterations in electrical activity on a whole-brain scale. Future studies should further confirm the effect of TAPB on cortical responses in broader populations, examine the correlation between intraoperative EEG characteristics and postoperative prognosis, integrate whole-brain EEG mapping to enhance spatial resolution, and explore the feasibility of personalized analgesic protocols guided by real-time EEG feedback.

5 Conclusions

In summary, this study provides neurophysiological evidence that the TAPB substantially modulates incision- and pneumoperitoneum-related cortical response, captured by multidimensional EEG characterization, thereby offering a novel objective approach for intraoperative analgesia assessment. Moreover, our findings indicate the efficacy of TAPB on somatic stimulation and limited modulation on visceral mechanical stimulation, which highlights the importance of optimizing multimodal analgesic regimens to better address intra- and postoperative pain control.

Declarations

Abbreviations

Not applicable.

Ethics approval and consent to participate

This study was registered in the Chinese Clinical Trial Registry (ChiCTR2400092228) after the approvement by the Ethics Committee of the Second Hospital of Anhui Medical University (reference number YX2023-088, date of approval 9/6/2023). All methods were carried out in accordance with the Declaration of Helsinki and its later amendments. The requirement for informed consent from individual participants was waived by the ethics committee, as this was a retrospective observational study using de-identified clinical data.

Consent for publication

Not applicable.

Competing Interests

All authors declare that there are no financial interests or personal relationships that could potentially affect the objectivity of this study during its design, implementation, data collection and analysis, and manuscript writing.

Funding

This study was supported by the following grants:

• National Natural Science Foundation of China (Grant No.: 82300945)

• Excellent Youth Research Project in Universities of Anhui Province from the Department of Education of Anhui Province (Grant No.: 2024AH030026)

• Research Fund of Anhui Institute of Translational Medicine (Grant No.: 2022zhyx-C53)

• Key Projects of Higher Education Scientific Research from the Department of Education of Anhui Province (Grant No.: 2023AH053160)

Author Contribution

WL, CXH, QX, and XXS conceived and designed the study. JYW, YZ, MYY, HM, BLJ, QX, ZHS, and XXS acquired, analysed, or interpreted the data. WL, CXH, ZHS, JYW, YZ, QX, and XXS drafted the manuscript. HL and YZ critically reviewed the manuscript for important intellectual content. CXH, QX, and XXS performed the statistical analysis. CXH, BLJ, and QX acquired funding. ZHS, JYW, and BLJ provided administrative, technical, or material support. CXH and QX supervised the study. All authors reviewed and approved the final manuscript.

Acknowledgement

Not applicable.

Data Availability

The datasets generated and/or analysed during the current study are not publicly available due to patient privacy restrictions, but are available from the corresponding author on reasonable request with approval from the institutional ethics committee.

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Figures

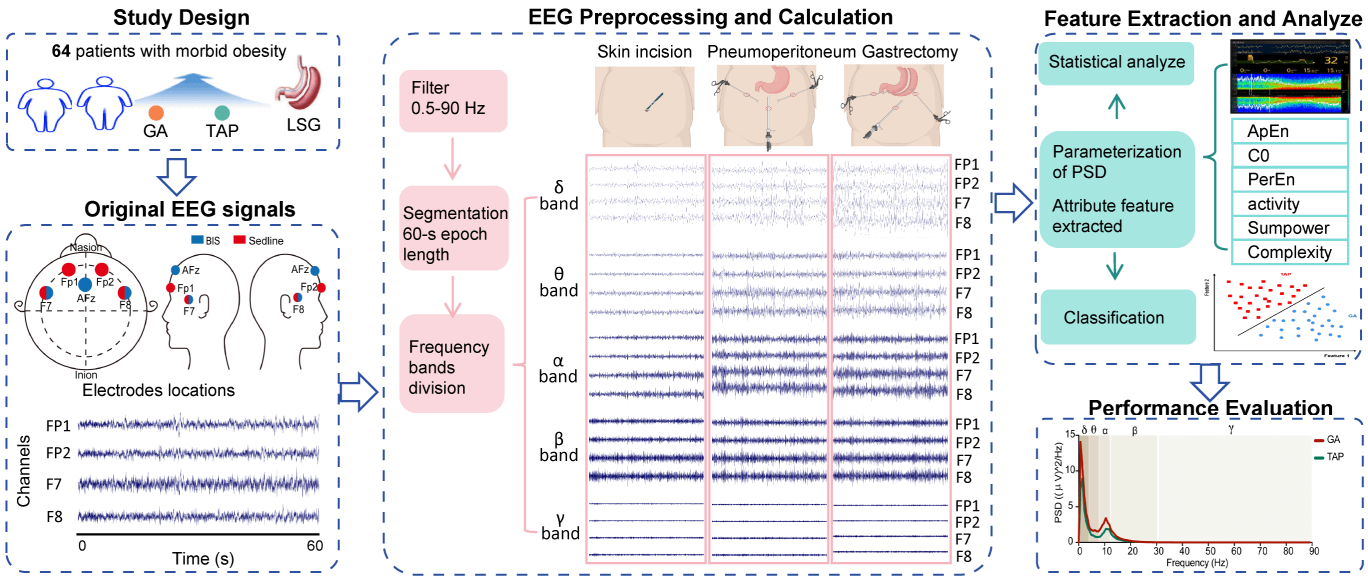


Figure 1

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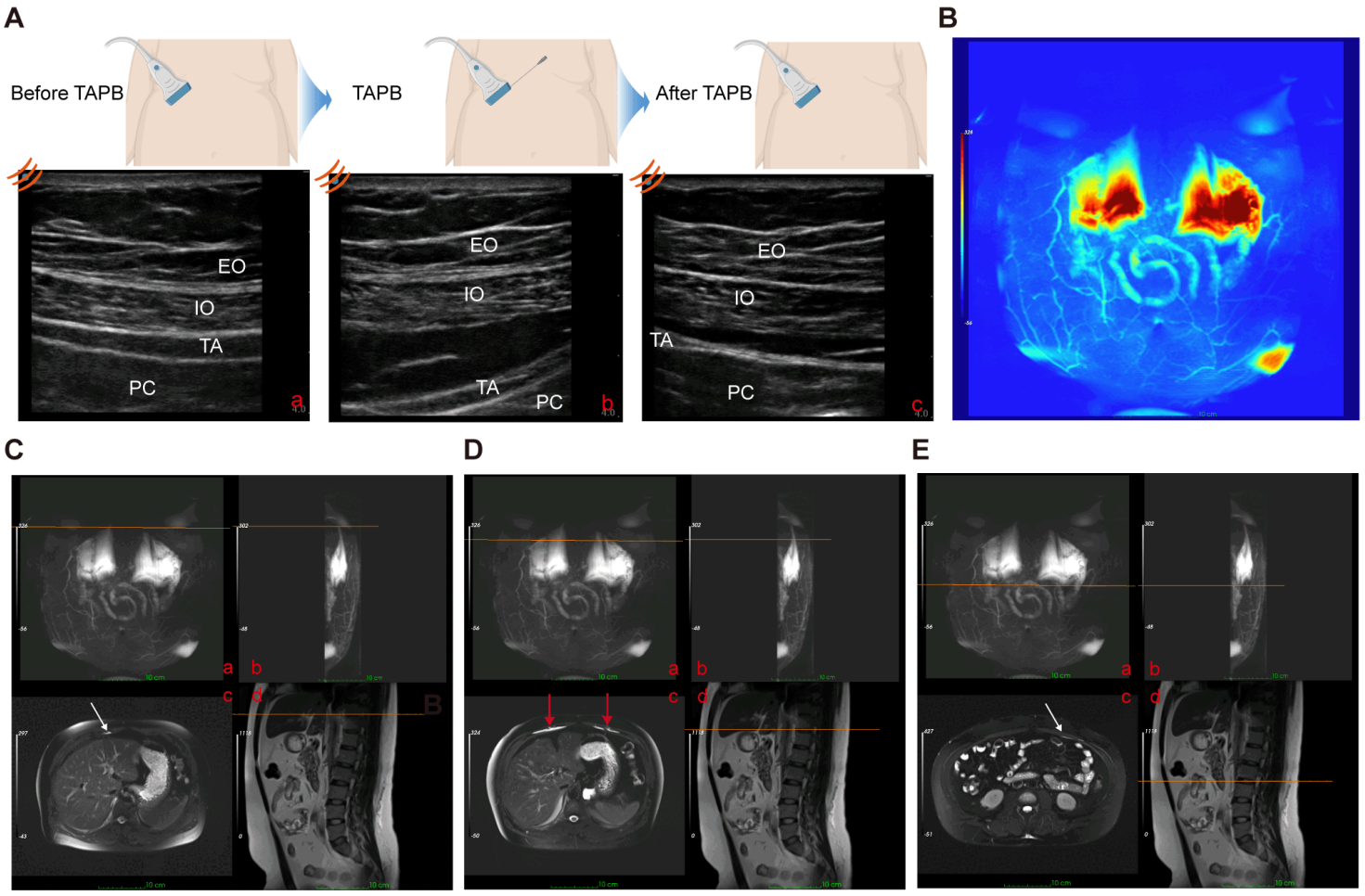


Figure 2

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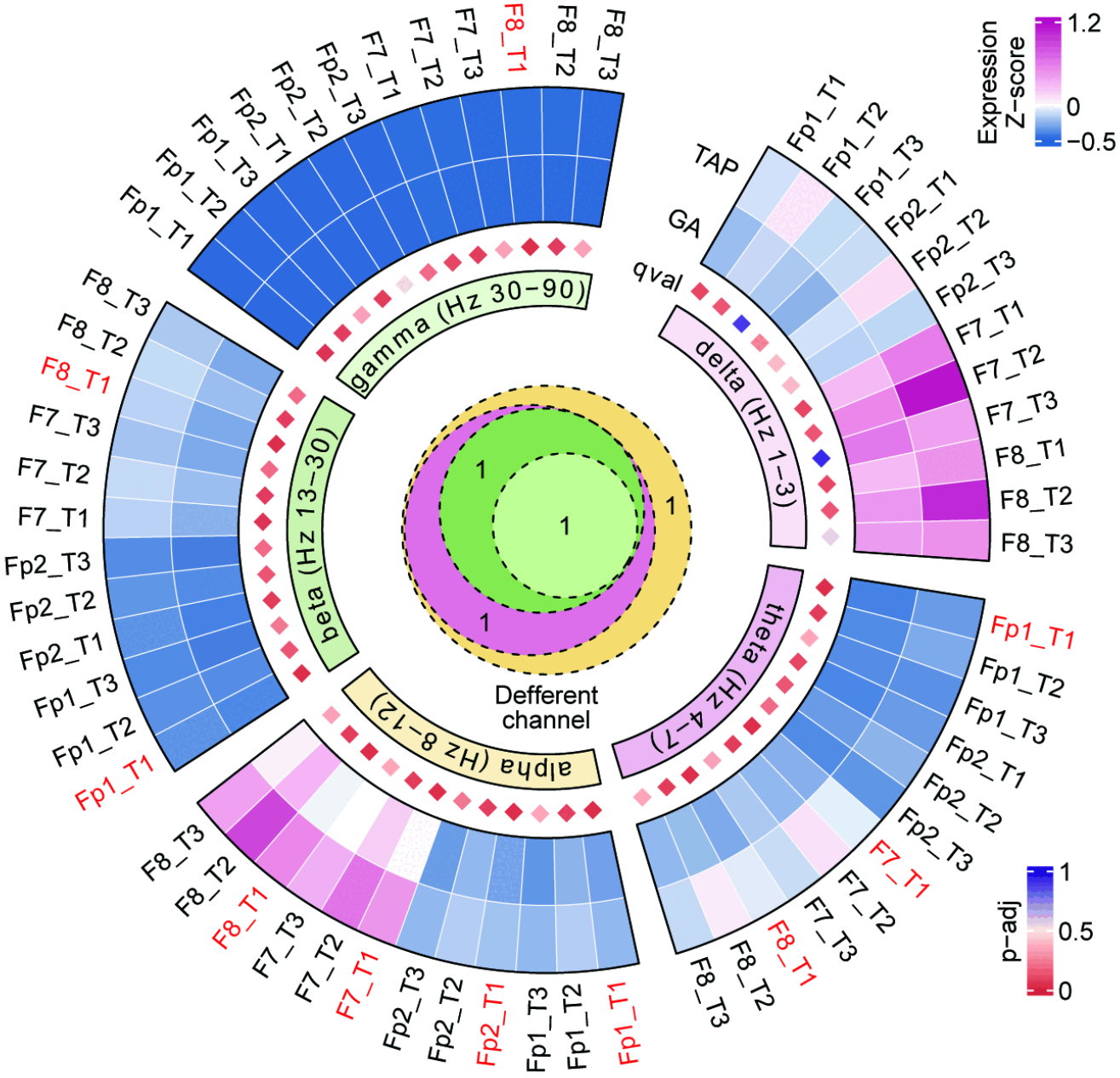


Figure 3

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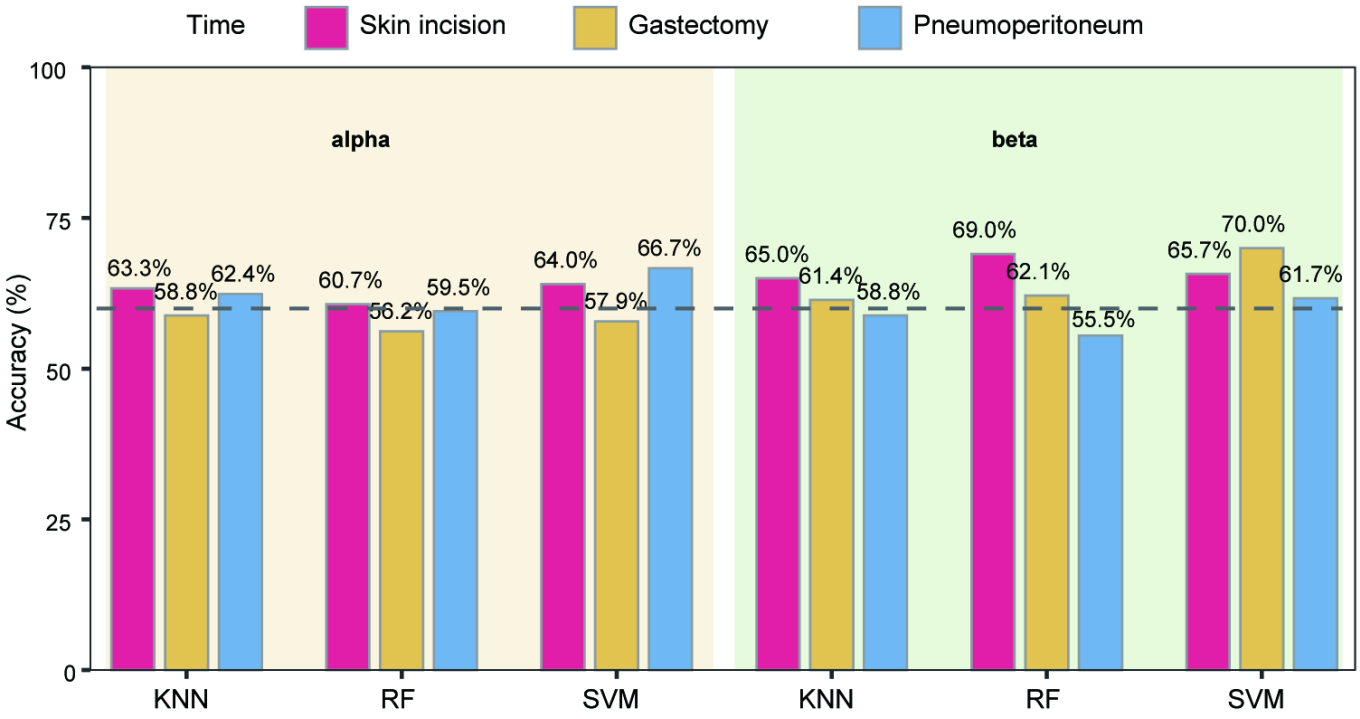


Figure 4

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