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ORIGINAL RESEARCH

Assessing Sedation Depth with PSI in Elderly ERCP Patients: A Prospective Cohort Study

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Background: Adequate sedation is important for elderly patients undergoing endoscopic retrograde cholangiopancreatography (ERCP). Patient state index (PSI) via the SedLine® system has been utilized for real-time monitoring of anesthesia depth in surgical patients. We aimed to assess the correlation between PSI and Modified Observer's Assessment of Alertness/Sedation (MOAA/S) scores in elderly patients undergoing ERCP.

Methods: This prospective cohort study included 57 elderly patients scheduled for ERCP procedures. Patients received target-controlled infusion of propofol, titrated to the sedation level of MOAA/S scores of 1 and 2. The MOAA/S scores and PSI values were recorded during sedation and recovery. We also documented procedure and recovery time, oversedation (PSI < 25 for at least 10 min and EEG burst suppression), adverse events, and fatigue scores (0–10, higher scores indicating more fatigue).

Results: All patients completed this study (mean age of 73 years and 63% male), with a mean procedure time of 53 min and recovery time of 37 min. Five patients (8.8%) experienced PSI < 25 for at least 10 min, and three of them (5.3%) showed EEG burst suppression. No patients developed desaturation or intra-procedural awareness. Hypotension and abdominal pain were uncommon. Nine patients (15.8%) experienced mild dizziness or nausea. The median (IQR) fatigue score was 3 (2–4) at recovery room discharge. A significant correlation was observed between the MOAA/S scores and PSI values (Spearman correlation coefficient $\rho = 0.742$, $P < 0.001$). When patients were at the MOAA/S scores of 1 and 2, the median PSI was 50 (95% CI: 48 to 52).

Conclusion: PSI provides a useful and real-time monitoring of sedation for elderly patients undergoing ERCP. Our results showed a significant correlation between the PSI values and MOAA/S scores and suggested a PSI value of 50 with a range of 48 to 52 for maintaining adequate sedation.

Trial Registration: Chinese Clinical Trial Registry (ChiCTR2400079859).

Keywords: endoscopic retrograde cholangiopancreatography, depth of sedation, elderly patients, Modified Observer's Assessment of Alertness/Sedation, patient state index

Introduction

Endoscopic retrograde cholangiopancreatography (ERCP) is widely performed for diagnosis and treatment of pancreaticobiliary disease.[1,2] These procedures are invasive and require patients to remain motionless with significant uncomfortableness. Propofol is the most commonly used sedative for ERCP but is associated with complications such as hypoxemia (~40%) and hypotension (~20%).[3,4] Many patients undergoing ERCP are elderly patients with multiple comorbidities who are prone to these complications, especially when over-sedated. Thus, adequate sedation with real-time monitoring is critical for ensuring successful and safe ERCP procedures in elderly patients.[5]

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Depth of sedation during endoscopic procedures is currently assessed using the subjective scales such as Modified Observer's Assessment of Alertness/Sedation (MOAA/S) scale or the Richmond Agitation-Sedation Scale (RASS).[6] However, these methods do not provide real-time monitoring, require repeated physical patient stimulations, and are difficult to detect oversedation. Recent advancements in sedation depth monitoring include the bispectral index (BIS) and patient state index (PSI). While BIS is widely used in anesthesia management, it has several limitations such as susceptibility to electromyographic interference, lack of raw electroencephalogram (EEG) data display, and reduced accuracy in deep sedation, especially in elderly patients undergoing endoscopic procedures. In recent years, the SedLine® system has been introduced for continuous monitoring of sedation and anesthesia depth. This system analyzes raw EEG signals to illustrate important information including density spectral array (DSA), spectral edge frequency (SEF), and patient state index (PSI), enabling more precise detection of sedation depth. A recent study suggested that PSI correlated well with RASS scores during sedation in endoscopic procedures.[7] The recommended PSI range for maintaining an adequate depth of anesthesia is 25–50; however, the PSI target for sedation during ERCP is unknown.

Our recent study demonstrated that a low dose of esketamine combined with propofol reduced the incidence of hypoxemia and hypotension, making it a safe sedation strategy for elderly patients.[6] Herein, we designed this study to investigate the relationship between MOAA/S scores and PSI during esketamine-propofol sedation in elderly patients undergoing ERCP. We also aimed to determine a PSI target that can be used to guide adequate sedation in these patients.

Methods

Study Design and Ethics

This prospective observational cohort study was conducted at the First Affiliated Hospital of Soochow University, Suzhou, China. The study was approved by the Medical Ethics Committee (Approval No. 2024–013) on January 10, 2024 and was registered at the Chinese Clinical Trial Registry (Identifier: ChiCTR2400079859; available at: https://www.chictr.org.cn/showproj.html?proj=217790) on January 15, 2024. Written informed consent was obtained from all patients or their legal guardians. All procedures adhered to the Declaration of Helsinki. The implementation and reporting of this study followed Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guideline (Supplemental File 1).[8]

Patient Selection

We included male and female patients aged ≥ 60 years with ASA classification I–III undergoing ERCP. Exclusion criteria were (1) severe bradycardia (heart rate < 50 beats/min), coronary heart disease, left ventricular ejection fraction < 30%, pulmonary infection, chronic obstructive respiratory disease, or asthma; (2) severe liver and kidney dysfunction (Child-Pugh grade C and requiring renal replacement therapy); (3) BMI < 18 or > 35 kg/m²; (4) anticipated airway difficulties; (5) contraindications to the medications used in this study; (6) mental illnesses, long-term use of sedative and analgesic drugs, or alcohol abuse; or (7) inability to communicate with research staff.

Sedation Protocol

All patients fasted for at least 8 h prior to the procedures. Upon arrival at the endoscopy suite, patients received oral lidocaine gel. Heart rate, non-invasive blood pressure, and peripheral oxygen saturation (SpO_2) were continuously monitored. A PSI sensor (SedLine®, Masimo, Irvine, CA) was placed on patients' forehead after skin preparation with alcohol to ensure optimal signal quality. Patients received oxygen supplementation of 5 L/min via a nasal cannula during the procedures and their recovery course. For induction of sedation, patients received an intravenous injection of esketamine 0.25 mg/kg and a target-controlled infusion (TCI) of propofol at a plasma concentration of 2.5 μg/mL (AstraZeneca, Macclesfield, UK). These dosages were based on our preliminary clinical observation and were in line with the literature.[9] The benefits of using esketamine as an adjuvant to propofol sedation has been demonstrated in our recent study.[6]

Level of sedation was assessed using the MOAA/S scale, with a range from 0 (unresponsive to stimuli) to 5 (awake and alert). At the start of ERCP, the sedation target level was a MOAA/S score of 1 (responding to a painful stimulus such as trapezius squeeze); during the procedures, the target was a score of 2 (responding to a shaking stimulus). If the MOAA/S score was higher than 2, the TCI propofol concentration was increased in steps of 0.5 μg/mL. If the MOAA/S score was lower than 1

or patients showed signs of airway obstruction, the concentration was decreased in steps of 0.5 μg/mL or stopped. Propofol infusion was discontinued immediately at the end of procedures, and patients were transferred to a recovery room. After patients were fully awake and achieved a MOAA/S score of 5, they were discharged from the recovery room to the wards. All ERCP and sedation procedures were performed by the same endoscopist and anesthesia team.

Data Collection and Outcome Measures

Before the procedures, we reviewed patients' electronic medical records and collected the characteristic data including age, sex, height, weight, BMI, ASA physical status, education level, and history of hypertension and diabetes.

The primary outcome measures were the MOAA/S scores and PSI values. The MOAA/S scores were assessed and documented every minute until reaching the target sedation level and every 5 minutes thereafter, and the corresponding PSI values were also recorded. Other outcome measures included procedure time, recovery time (from the end of procedures to discharge from recovery room), PSI < 25 for at least 10 min, EEG burst suppression, desaturation (SpO_2 < 90% for at least 10 seconds), hypotension (a decrease in mean blood pressure > 20% from baseline), awareness during procedures, abdominal pain, dizziness or nausea, vomiting, and fatigue scores (ranging from 0 to 10, with 0 indicating no fatigue and 10 indicating the most severe fatigue).

Sample Size Estimation

A previous study suggested that the PSI values were significantly associated with the MOAA/S scores in the Pearson's correlation analysis (r = 0.39).[10] We used the PASS software (version 15.0.5, NCSS, LCC, Kaysville, UT, USA) to estimate that at least 49 patients were needed to detect such as correlation with a two-sided α level of 0.05 and a power of 80%. Considering possible attrition (~15%) which was based on our previous clinical observations, we planned to enroll a total of 59 elderly patients undergoing ERCP.

Statistical Analysis

The Shapiro–Wilk test was used to assess whether continuous variables were normally distributed. Variables with normal distribution are presented as mean ± standard deviation (SD), while non-normally distributed variables are shown as median (interquartile range [IQR]). Categorical variables are expressed as number (%). Descriptive statistics were applied for all data. Correlation of the MOAA/S scores and PSI values was assessed using the Spearman's rank correlation analysis, with the correlation coefficient (ρ) and significance being reported. The PSI values when patients were at different MOAA/S scores were plotted using a box plot. The PSI values at the MOAA/S scores of 1 and 2 were plotted using a violin plot, and the median PSI values with 95% confidence interval (CI) and 25% and 75% percentiles were analyzed. All statistical analyses were conducted using the SPSS software (IBM SPSS Statistics, version 23, Chicago, IL, USA). A two-sided $P < 0.05$ indicates a statistically significant difference.

Results

Study Flow and Patient Characteristics

From January to May 2024, a total of 119 elderly patients undergoing ERCP were assessed for eligibility (Figure 1). Of them, 60 patients were excluded and 59 patients were enrolled. Two patients underwent unplanned tracheal intubation and general anesthesia. Finally, 57 patients completed this study and their data were analyzed (Table 1). The (mean ± SD) age was 73.1 ± 8.7 years, and 63.2% of patients were male. Most patients (98.2%) were at ASA physical status II.

Procedure and Recovery Characteristics

For these patients, the (mean ± SD) procedure time was 52.7 ± 35.1 min, and the recovery time was 36.6 ± 7.6 min (Table 2). Five patients (8.8%) experienced PSI values < 25 for longer than 10 min, while three of them (5.3%) showed EEG burst suppression. No desaturation events occurred. Hypotension and abdominal pain were uncommon. No patients reported awareness during the procedures. Nine patients (15.8%) experienced mild symptoms of dizziness or nausea during recovery. The median (IQR) fatigue score was 3 (2–4) at the time of recovery room discharge. For patients who

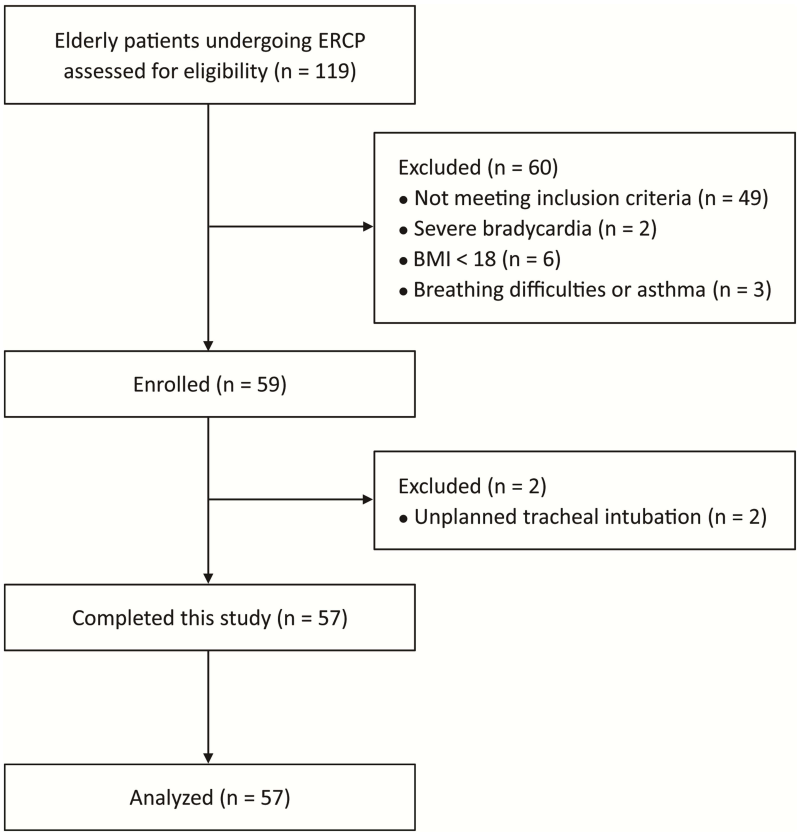

Figure 1 Study flow diagram.
Abbreviations: BMI, body mass index; ERCP, endoscopic retrograde cholangiopancreatography.

showed oversedation, propofol infusion was immediately reduced or paused, and patients were closely monitored for airway patency. Hypotension was managed with intravenous fluids and, if needed, vasopressors. Nausea or dizziness during recovery was addressed symptomatically with antiemetics and patient reassurance.

Table 1 Patient Characteristics

	Patients (n = 57)
Age (years)	73.1 ± 8.7
Sex	
Male	36 (63.2%)
Female	21 (36.8%)
Height (cm)	163.6 ± 7.1
Weight (kg)	60.1 ± 10.2
BMI (kg/m²)	22.4 ± 3.1
ASA physical status	
I	0
II	56 (98.2%)
III	1 (1.8%)
Education level	
Illiteracy	11 (19.3%)
Primary	19 (33.3%)
Secondary or higher	27 (47.4%)
Hypertension	25 (43.9%)
Diabetes	17 (29.8%)

Note: Data are mean ± standard deviation or number (%).
Abbreviation: BMI, body mass index.

Table 2 Procedure Time, Recovery Time, and Adverse Events

	Patients (n = 57)
Procedure time (min)	52.7 ± 35.1
Recovery time (min)	36.6 ± 7.6
PSI < 25 for longer than 10 min	5 (8.8%)
EEG burst suppression	3 (5.3%)
Desaturation	0
Hypotension	4 (7%)
Awareness during procedures	0
Abdominal pain	5 (8.8%)
Dizziness or nausea	9 (15.8%)
Vomiting	0
Fatigue score at recovery room discharge [a]	3 (2–4)

Notes: Data are mean ± standard deviation, median (interquartile range), or number (%). [a]Fatigue scores ranged from 0 (no fatigue) to 10 (the most severe fatigue).
Abbreviations: PSI, patient state index; EEG, electroencephalogram.

EEG Data and Sedation Levels

Figure 2 illustrates the characteristics of sedation in a representative patient (male, 60 years old). The changes in the PSI values and MOAA/S scores during the entire course of sedation and recovery are shown in Figure 2A. Propofol

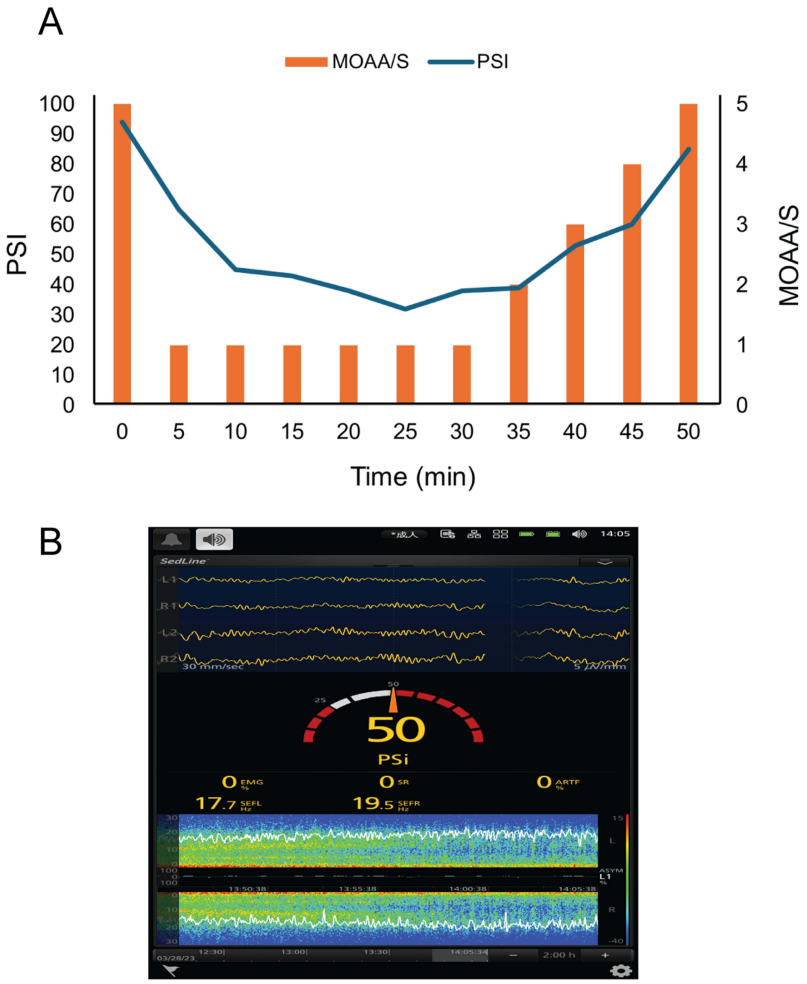

Figure 2 Characteristics of sedation in a representative patient. (**A**) Changes in PSI values and MOAA/S scores during sedation and recovery. **(B)** Electroencephalographic image captured by the SedLine® monitor. The PSI and MOAA/S scores over time illustrate the progression of sedation and recovery in this patient.
Abbreviations: MOAA/S, Modified Observer's Assessment of Alertness/Sedation; PSI, patient state index.

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infusion was started at time "0" (the beginning of sedation induction). The MOAA/S sedation scores decreased from 5 to 1 in 5 min, corresponding to a decrease in the PSI values from 94 to 65. The ERCP procedure was completed at 32 min, and the propofol infusion was stopped. The patient was transferred from the endoscopy suite to the recovery room. The MOAA/S score and PSI value gradually increased. At the time of 50 min, the patient was fully awake with the MOAA/S score of 5 and the PSI value of 85, and then the patient was ready for recovery room discharge to the ward.

Figure 2B shows the EEG image captured by the SedLine® monitor, including raw EEG waves, PSI value, left and right SEF values, and DSA power spectra. For this patient, the SEF values ranged from 15 to 20 during sedation. At the time of endoscopy suite discharge, the PSI value was 50 and the MOAA/S score was 2.

Correlation Between the PSI Values and MOAA/S Scores

Figure 3 shows the PSI values when patients were at different MOAA/S scores of 1–5. The median (IQR) of PSI values were 52 (41–63), 73 (64–81), 75 (68–82), 81 (75–85), and 88 (85–93) corresponding to the MOAA/S scores of 1, 2, 3, 4, and 5, respectively. In the Spearman correlation analysis, there was a significant correlation between the PSI values and MOAA/S scores ($\rho = 0.742$, $P < 0.001$).

PSI Target for Maintaining Adequate Sedation During ERCP

To obtain a PSI target used for maintaining an adequate level of sedation in elderly patients undergoing ERCP procedures, we analyzed the PSI values during sedation when patients were at the MOAA/S scores of 1 and 2 (Figure 4). The results showed that the median PSI was 50 (95% CI: 48 to 52), with the quartile 1 of 39 and quartile 3 of 60.

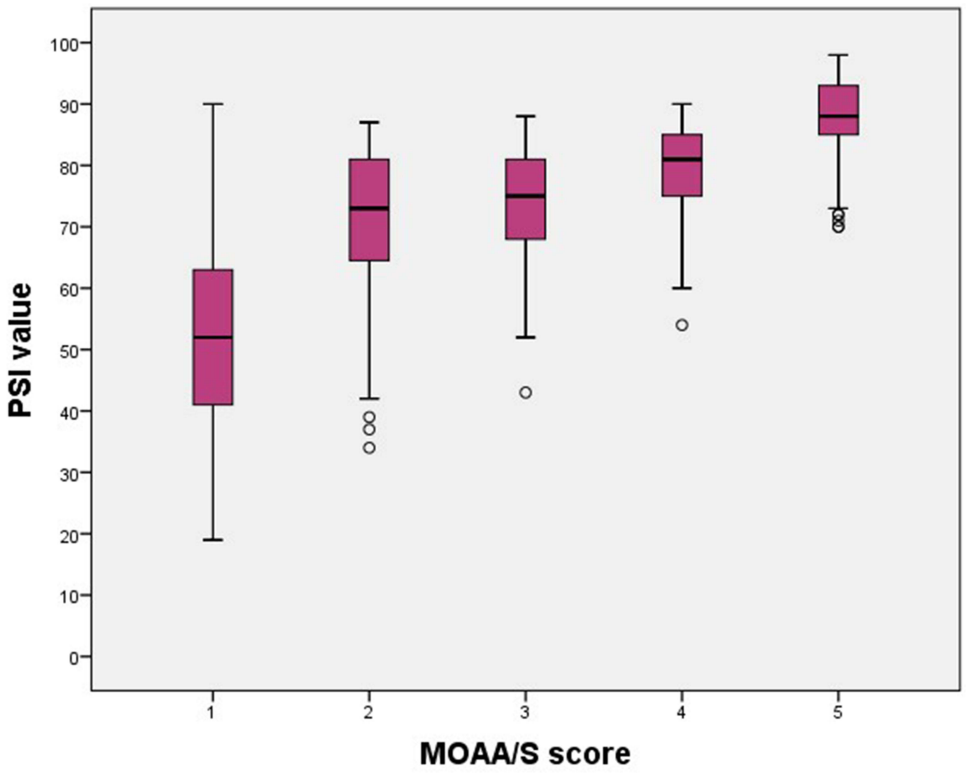

Figure 3 PSI values at MOAA/S scores of 1–5.
Abbreviations: MOAA/S, Modified Observer's Assessment of Alertness/Sedation; PSI, patient state index.

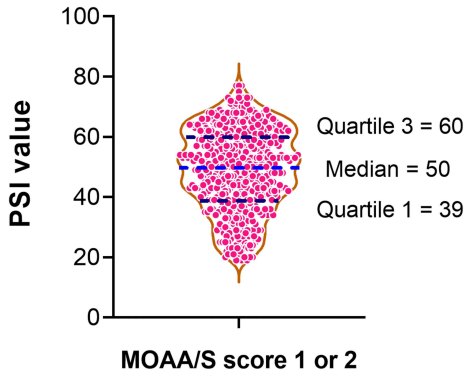

Figure 4 Distribution of PSI values corresponding to MOAA/S scores of 1 and 2. The distribution of PSI suggests that targeting a PSI value of 50 may be suitable for adequate sedation.
Abbreviations: MOAA/S, Modified Observer's Assessment of Alertness/Sedation; PSI, patient state index.

Discussion

In this prospective cohort study, we included 57 elderly patients undergoing ERCP procedures under esketamine-propofol sedation. We assessed the depth of sedation using the MOAA/S method and PSI via the SedLine® system. Our results showed a significant correlation between the PSI values and MOAA/S scores. Moreover, the median PSI value was 50 (95% CI: 48 to 52) when the patients had MOAA/S scores of 1 and 2 (an adequate depth of sedation). Our study is the first to explore the optimal PSI range in elderly patients undergoing ERCP, suggesting that a PSI target of 50 would be adequate for sedation.

In endoscopic procedures, depth of sedation is typically assessed using the sedation scales such as MOAA/S. However, MOAA/S assessment requires repeated stimuli to the patient, which can alter the sedation level and affect the EEG monitoring results.[11] Studies have shown that even subtle stimuli significantly increased the changes in simulated EEG values for all commercial EEG measures.[12,13] BIS is the most widely used tool for monitoring anesthesia depth, and general anesthesia is commonly maintained with BIS values of 40–60 during surgery. Nonetheless, BIS is not without limitations: (1) it is affected by electromyographic activity;[14] and (2) it provides only a processed numerical value without displaying raw EEG data. Compared to BIS, PSI offers several distinct advantages for sedation depth monitoring. First, PSI displays raw EEG data alongside processed numerical indices, allowing clinicians to validate the sedation depth against EEG patterns. Second, PSI is less affected by electromyographic activity. Third, recent studies have suggested that PSI provides superior accuracy in predicting sedation depth compared to BIS, particularly in scenarios involving deep sedation during endoscopic procedures.[7] These features make PSI a more suitable tool for individualized sedation management, especially in elderly patients, as demonstrated in this study. Future research should include direct comparative studies between PSI and BIS to further validate these findings.

The SedLine® system provides a continuous monitoring of sedation depth. For surgical patients under general anesthesia, a PSI range of 25–50 indicates appropriate anesthesia depth. Low PSI values and the occurrence of burst suppression are timely indicators of oversedation. Oversedation (PSI < 25 for at least 10 min and EEG burst suppression) was observed in 8.8% of the elderly patients in our study. We believed that using this SedLine® system helps to reduce the risk of oversedation and related complications, which makes it more suitable for monitoring sedation in elderly patients undergoing ERCP compared with the MOAA/S.[15] We propose that the measures to reduce the risks of oversedation include (1) using PSI as a real-time monitoring tool to adjust sedation levels dynamically; (2) early intervention and titration of sedative doses to achieve the required sedation level; and (3) highlighting the need for individualized precise sedation management to minimize oversedation and prevent complications in elderly patients.

In our previous study, the esketamine-propofol combination was used for sedation in patients who underwent gastrointestinal endoscopy. This regimen was proven to be safe and effective, reducing the incidence of hypotension and hypoxemia.[6] In the current study, only a small number of patients (7.0%) experienced hypotension, and no desaturation events occurred. Oversedation events included PSI < 25 (8.8%) and EEG burst suppression (5.3%). Of

note, sedation in this study was guided by the MOAA/S scores rather than PSI values. The median fatigue score of 3 (IQR: 2–4) at recovery room discharge indicated mild fatigue experience of our patients. This could reflect residual sedation and the impact on physiological demands by the procedures. Future research should focus on whether using PSI to guide sedation could reduce the risk of oversedation and optimize sedation management (such as reducing fatigue and improving recovery) in elderly patients undergoing endoscopic procedures.

This study has several limitations. First, the esketamine-propofol sedation regimen was used for our patients, so the correlation between PSI and MOAA/S scores with other sedatives (such as remimazolam, ciprofol, and dexmedetomidine) requires further investigation. Second, this study is limited by its single-center design and lack of a control group, which restrict the generalizability of the findings. Future studies should focus on PSI-guided sedation protocols and comparative analyses with a control group using traditional monitoring methods (eg, BIS). Next, the short study duration (January–May 2024) also limits the generalizability of the findings, and future studies with extended timelines are recommended. Last, this study did not have long-term outcome measures such as postoperative delirium, cognitive decline, or overall recovery trajectories. These are critical in elderly populations and warrant investigation in future studies.

In summary, this study found a significant correlation between PSI and MOAA/S scores during sedation in elderly patients who underwent ERCP. The median PSI value was 50 (95% CI of 48 to 52) for maintaining adequate sedation. Our findings support further research to explore the use of PSI monitoring for titrating sedation in elderly patients undergoing endoscopic procedures.

Data Sharing Statement

All data and materials generated or used in this study (including individual deidentified participant data, Case Report Form, and Informed Consent Form) are available upon reasonable request to the corresponding author. Data can be accessible after the publication of this article without time limit.

Assistance with the Study

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Disclosure

The authors report no conflicts of interest in this work.

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