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TITLE PAGE

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Abstract

This retrospective observational study, involving 92 women undergoing hysteroscopy under procedural sedation from a clinical trial (NCT05263791), quantified the contribution of partial airway obstruction to oxygen desaturation (OD) during procedural sedation relative to apnea, and validated a previously trained convolutional bi-directional gated recurrent unit (CNN-BiGRU) model for automated detection of obstruction sound episodes (OSEs) via digital tracheal auscultation. Participants experienced 337 apneas, 277 OSEs, 21 subtle OD events, and 10 mild short OD events. Within 1- and 2-minute windows preceding subtle OD, OSEs were observed in 13 (62%) and 15 (71%) instances, numerically higher than apnea (7 [33%] and 9 [43%]); the same pattern was observed before mild short OD, with OSEs present in 4 (40%) and 7 (70%) instances versus apnea in 3 (30%) and 3 (30%). The OSE detection algorithm achieved a sensitivity of 0.704 (95% CI, 0.635 to 0.773), PPV of 0.813 (95% CI, 0.749 to 0.871), and F1 score of 0.754 (95% CI, 0.697 to 0.807) at the optimal threshold of 0.80. Partial airway obstruction frequently precedes OD during procedural sedation, often without concurrent apnea. The proposed algorithm enables automated monitoring of partial airway obstruction during procedural sedation.

Keywords: deep learning; partial airway obstruction; procedural sedation; respiratory monitoring; tracheal auscultation

Introduction

Over the past two to three decades, diagnostic and therapeutic procedures have increasingly been performed under procedural sedation in non-operating room settings rather than under conventional general anesthesia. This approach facilitates faster recovery and same-day discharge [1,2] and may reduce overall costs compared with general anesthesia [3-6].

However, procedural sedation carries inherent risks. Many sedatives, such as propofol and midazolam, can cause respiratory depression by suppressing respiratory drive, leading to central apnea or hypopnea, or by reducing upper airway muscle tone, resulting in partial or total airway obstruction [1]. These respiratory events can subsequently lead to oxygen desaturation (OD) or hypoxemia (Figure 1).

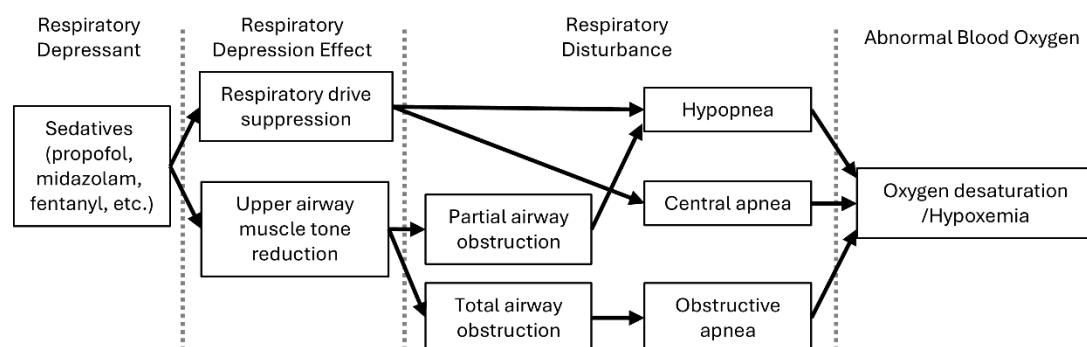


Figure 1. Causal mechanism of sedative-induced respiratory pathophysiology.

If unrecognized, sedation-induced adverse respiratory events (AREs) may lead to severe patient harm. A closed-claims study indicated that 68% of deaths or brain injuries in non-operating room anesthesia were attributed to AREs [7]. Thus, earlier detection of AREs is important to prevent cascading consequences and severe outcomes.

Pre-cordial or pre-tracheal auscultation is a conventional technique recommended or required by many clinical guidelines [8-11] and U.S. state regulations [12-14] for monitoring patient ventilation during procedural sedation. The importance of continuous respiratory monitoring was further emphasized by Caleb's Law in California, USA, which strengthened requirements for continuous auscultation during pediatric sedation [15]. However, continuous manual auscultation is labor-intensive and prone to human error when clinicians multitask; furthermore, for many procedures performed under procedural sedation, sedation is administered and monitored by the proceduralist rather than a dedicated anesthesiologist or anesthesia-trained provider, leaving auscultation even more impractical. These reasons highlight the need for automated acoustic monitoring.

Computerized respiratory sound analysis has been used to detect breathing phases [16], apnea in tracheal sounds during sedation [17,18], and acoustic respiratory rate with apnea alarms [19,20]. Nevertheless, few studies have validated obstruction sound

episode (OSE) detection models for monitoring partial airway obstruction during procedural sedation. In addition, the relative contribution of partial airway obstruction versus apnea to OD, and the temporal relationship between sedative bolus injection and these respiratory events, remains insufficiently understood.

In this study, we conducted a retrospective analysis using data from a clinical trial, “Evaluating the Non-Inferiority of Airmod to Capnostream™ 35” (ClinicalTrials.gov identifier: NCT05263791) [20]. We aimed to: (1) investigate the extent to which partial airway obstruction contributes to OD during procedural sedation relative to apnea, and its temporal association with sedative bolus injection, and (2) validate a deep learning–based OSE detection algorithm based on a previously proposed convolutional bi-directional gated recurrent unit (CNN-BiGRU) network [21] for monitoring partial airway obstruction during procedural sedation.

Materials and Methods

Study Design and Data Source

This was a retrospective observational study using data from Cathay General Hospital, Taipei, Taiwan, one of three centers that participated in the original clinical trial (ClinicalTrials.gov identifier: NCT05263791) [20]. The study protocol was approved by the Institutional Review Board of Cathay General Hospital, Taipei,

Taiwan, in December 2021 (IRB No. CGH-CS110008). All participants provided written informed consent before enrollment. The data were collected between February 2022 and September 2022. The retrospective analysis was conducted between June 2025 and September 2025. A data analysis and statistical plan was written after the data were accessed. This study was reported in accordance with the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines.

Study Population

Adult women scheduled for hysteroscopy procedures with procedural sedation were recruited from the obstetrics and gynecology clinic at Cathay General Hospital.

Inclusion criteria were: (1) signed informed consent, (2) willingness to participate in all study procedures, (3) age ≥ 20 years, and (4) suitability for procedural sedation.

Exclusion criteria included: (1) neck pain or injuries, (2) use of high-flow nasal cannula ventilation, (3) inability to wear device accessories, (4) vulnerable population status, and (5) unwillingness or inability to comply with study procedures. A total of 103 women scheduled for a diagnostic, therapeutic, or see-and-treat hysteroscopy procedure were recruited.

Tracheal Sound Recording and SpO₂ Measurement During Procedural Sedation

An acoustic sensor from an electronic stethoscope (AS-101, Heroic Faith International Ltd., New Taipei, Taiwan) was attached to the flat area adjacent to the subjects' thyroid cartilage for tracheal auscultation during the procedure. Tracheal sounds were transmitted to and recorded by Airmod (Heroic Faith International Ltd., New Taipei, Taiwan), an AI-powered Respiratory MOnitor Device that has since received US FDA clearance for respiratory monitoring during anesthesia and procedural sedation. Tracheal sounds were sampled at 4,000 Hz and saved in WAVE (.wav) format. SpO₂ was measured using a capnogram (Capnostream 35, Medtronic, Minneapolis, USA).

Procedural sedation was performed using either bolus or target-controlled infusion (TCI), depending on the individual anesthesia plan. A combination of fentanyl (25–50 µg), propofol (50–180 mg), and/or midazolam (0.5–3 mg) was administered to induce sedation. When manual infusion was used, intermittent boluses of propofol (20–50 mg) were administered to maintain sedation; when TCI was used, propofol was administered at 20–35 mL · hr⁻¹ via a TCI pump. The exact dose was participant-dependent and determined by the anesthesia practitioner. The sedation level was maintained at a moderate level for the majority of the procedure. Supplemental

oxygen was delivered via an oxygen mask at an initial rate of $2.5\text{--}11\text{ L} \cdot \text{min}^{-1}$ and maintained at approximately $5\text{--}7\text{ L} \cdot \text{min}^{-1}$ during the hysteroscopy procedure.

The hysteroscopic procedure was performed in accordance with standard clinical practice. Anesthesia practitioners adjusted oxygen flow and performed airway interventions, including airway positioning, manual ventilation, artificial airway placement, or conversion to general anesthesia, as clinically indicated. An on-site researcher continuously observed all monitors, the anesthesia practitioner, and the subjects during the procedure and recorded the occurrence of predefined events (see Supplementary Table S1 for the coding) in accordance with the study protocol.

After the procedure, subjects were transferred to the post-anesthesia care unit (PACU). The study observation period ended either when the subject's Post-Anesthesia Recovery Score returned to ≥ 9 or after 15 minutes in the PACU.

Obstruction Sound Event and Apnea Ground-Truth Labeling

Clinical experts (licensed respiratory therapists with prior experience in labeling respiratory sounds) labeled the start and end times of each obstruction sound (viewed as an event) by listening to the tracheal sound recordings and observing the spectrogram using custom labeling software [22]. The obstruction sound labels in this study included snoring originating from the upper airway and continuous adventitious sounds resulting from partial obstruction at the trachea or bronchi level, which might

have a quality analogous to stridor, rhonchus, or wheeze. The obstruction sound labels served as ground truth in this study. The clinical experts also labeled the start and end times of each apnea (cessation of breathing lasting ≥ 10 seconds) by listening to the recorded tracheal sound and observing the corresponding capnographic waveforms. We did not differentiate between central and obstructive apnea. To minimize labeling bias, all recordings were labeled with standardized criteria and reviewed for consistency. Labelers were blinded to the AI model outputs during the labeling process.

Adverse Respiratory Event Definitions

We used the reporting tool suggested by the World SIVA International Sedation Task Force [23] and the guidelines from the American Academy of Sleep Medicine [24], with some modifications, to define apnea, OSE, and OD.

Apnea was reported at three severity levels: short apnea (cessation of breathing ≥ 10 s and < 30 s), intermediate apnea (≥ 30 s and < 60 s), and prolonged apnea (≥ 60 s) [23]. The three categories of apnea were mutually exclusive.

Because a single obstruction sound event was unlikely to significantly affect SpO₂, we defined an OSE as a sequence of at least five obstruction sound events, ending only when a gap of at least 30 seconds occurred between the last and next events.

OD was categorized into four types: (1) a subtle OD, defined as a decrease in SpO₂ of $\geq 3\%$ from a pre-event baseline (120-second rolling average) [24] that failed to return to within 1% of baseline (baseline – 1%) for at least 10 seconds (subsequent events were considered independent only when the SpO₂ in the previous desaturation returned to and remained above baseline – 1% for a stable period of ≥ 30 s); (2) a mild short OD, defined as SpO₂ 75–90% for < 60 s; (3) a mild long OD, defined as SpO₂ 75–90% for ≥ 60 s; and (4) a severe OD, defined as any SpO₂ $< 75\%$ [23]. For mild short OD, mild long OD, and severe OD, an event was considered independent if the SpO₂ below the threshold returned to 90% without regard to the stable period. The mild short OD, mild long OD, and severe OD were mutually exclusive; however, the subtle OD was not exclusive to the other three types of OD.

Contribution of Partial Airway Obstruction to OD

To investigate the extent to which partial airway obstruction contributes to the onset of OD relative to apnea during procedural sedation, and the temporal association of sedative bolus injection with these respiratory events and OD, we examined the number of instances in which at least one sedative bolus injection, apnea, and/or OSE was present within a 1- or 2-minute window before the OD. The 1- and 2-minute windows were chosen because OD is physiologically delayed by 25–40 seconds relative to the onset of respiratory depression; moreover, supplemental oxygen may

further blunt the SpO2 response. Sequence graphs were generated to display temporal associations with OD, and Venn diagrams were drawn to illustrate the joint contributions of these events to OD induction.

Automatic OSE Detection

We developed an AI inference script in Python for post-hoc analysis of the clinical trial data (Figure 2).

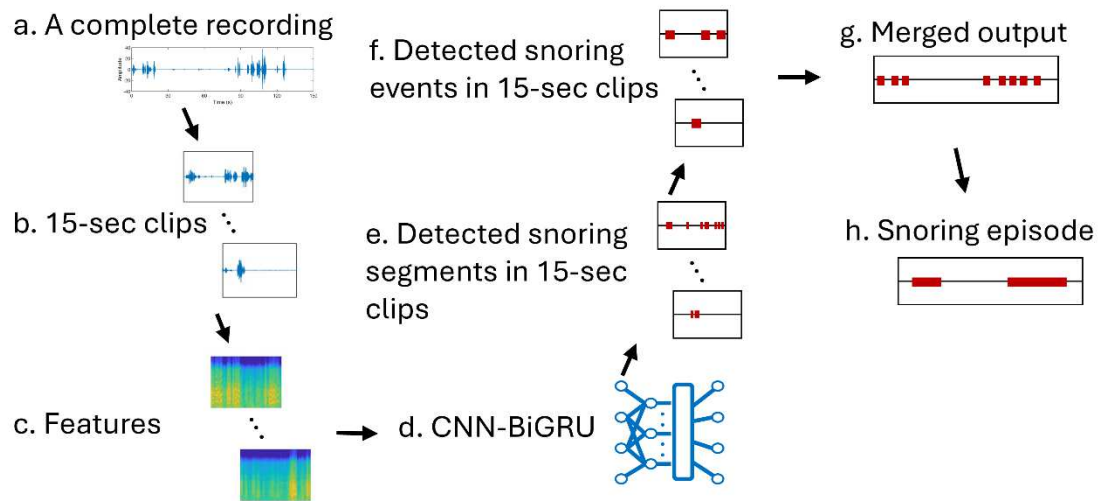


Figure 2. Flowchart of OSE detection using the previously proposed CNN-BiGRU model. (a) Complete tracheal sound recording; (b) sequential 15-s clips; (c) feature preprocessing; (d) CNN-BiGRU inference; (e) detected obstruction sound segments; (f) post-processing into obstruction sound events; (g) merging detections across clips; (h) AI-detected OSEs.

Each complete tracheal sound recording obtained in the trial (Figure 2a) was first truncated into a series of sequential, non-overlapping 15-second tracheal sound clips (Figure 2b). The clips were then preprocessed to generate features (Figure 2c), which were fed into the previously trained deep-learning-based CNN-BiGRU model (Figure 2d). Feature preparation followed the methodology described in our previous work [21]. Briefly, the features included a 938×129 spectrogram, a 938×60 mel-frequency cepstral coefficient array, and a 938×4 energy summation array. The model's output was the detected obstruction sound segments (Figure 2e). A post-processing step was then used to merge the neighboring segments into obstruction sound events and remove spurious segments (Figure 2f) [21]. The detection results from the adjacent 15-second clips were then merged into a complete recording (Figure 2g). Finally, we applied the same criteria that defined a ground-truth OSE (see subsection "Obstruction Sound Event and Apnea Ground-Truth Labeling") to produce the AI-detected OSEs (Figure 2h). AI inference was performed on a Mini PC (Intel NUC 11 PAHi5; Intel, Santa Clara, California, USA).

OSE Detection Performance Validation

We evaluated OSE detection performance using sensitivity (SEN), positive predictive value (PPV), and F1 score averaged across all subjects:

$$\text{SEN} = \text{TP} / (\text{TP} + \text{FN}) \quad (1)$$

$$\text{PPV} = \text{TP} / (\text{TP} + \text{FP}) \quad (2)$$

$$\text{F1 score} = 2 \times (\text{SEN} \times \text{PPV}) / (\text{SEN} + \text{PPV}) \quad (3)$$

Definitions of true positive (TP), false positive (FP), and false negative (FN) OSE detections are provided in Supplementary Materials (Section S2). Because the threshold value at the last layer of the CNN-BiGRU model influenced the output of obstruction sound segment detection, which in turn affected the representation of obstruction sound events and episodes after the post-processing step, we investigated performance across a range of thresholds from 0.05 to 0.95 with a step size of 0.05.

Statistical Analysis

McNemar's test [25] was used to compare the paired proportions of OSEs and apnea observed within the same time windows. To evaluate the precision of the OSE detection algorithm, 95% confidence intervals (CIs) for SEN, PPV, and F1 score were calculated using bootstrapping [26]. Participant-level resampling was repeated 1,000 times to account for inter-individual variability. The statistical analysis was performed using MATLAB (version 2020b; MathWorks, Natick, Massachusetts, USA).

Subjects with corrupted tracheal sound or EtCO₂ recordings that prevented reliable event labeling were excluded from analysis. No imputation was performed.

Ethics Approval and Consent to Participate

The study protocol was reviewed and approved by the Institutional Review Board of Cathay General Hospital, Taipei, Taiwan (IRB number: CGH-CS110008). All participants provided written informed consent prior to enrollment.

Generative AI Tools Use Statement

During the preparation of this manuscript, the authors used ChatGPT (OpenAI), Gemini (Google), and Grammarly to improve the language, grammar, and sentence structure of the text. After using these tools, the authors reviewed and edited the content as needed and take full responsibility for the publication's content. None of these tools were used to generate scientific content, analyze data, or formulate core ideas.

Results

One hundred women were eventually enrolled, and 92 subjects were included in the final analysis (1 subject was excluded per the exclusion criteria, and 7 subjects were excluded due to corrupted tracheal sound or EtCO₂ recordings). No other variables had missing data. The subjects were aged 43.3 (10.5) years and had a mean BMI of 23.1 (4.1) kg · m⁻². Sedation was maintained by manual injection of a propofol bolus in 89 subjects and by a TCI pump in the other three. Demographic and clinical characteristics are summarized in Table 1.

The average procedure duration was 21.5 (11.0) minutes. Table 2 lists the number of sedative bolus injections, ARE incidents, and airway management interventions in the subjects. The subjects experienced a total of 454 sedative bolus injections. Two hundred and seventy-seven ground-truth OSEs were labeled. Twenty-one subtle ODs and 10 mild short ODs were identified. No mild long OD or severe OD was observed. The experts labeled 218 short apneas, 88 intermediate apneas, and 31 prolonged apneas, for a total of 337 apnea events. During the procedure, 12 subjects had a nasal airway inserted; 434 airway-positioning maneuvers and 92 manual ventilation maneuvers were performed. No oral airway or laryngeal mask airway was used, and no tracheal intubation or conversion to general anesthesia occurred.

Table 3 lists the number of instances having at least a sedative bolus injection, apnea, or OSE within the 1- and 2-minute search windows preceding the 21 subtle ODs and 10 mild short ODs. Across both window lengths, sedative bolus injection and OSEs were present more frequently than apnea before both subtle and mild short OD events (subtle OD: OSE 62–71% vs. apnea 33–43%; mild short OD: OSE 40–70% vs. apnea 30%, across the 1- and 2-minute windows), although the difference in the number of OSEs and apneas within the 1- and 2-minute windows was not statistically significant for subtle OD ($P = 0.18$ for both windows) nor for mild short OD ($P = 1.00$ and $P = 0.22$, respectively). As shown in the sequence graphs for individual cases (Figures 3

and 4), OSEs frequently preceded OD, with several instances occurring without concurrent apnea.

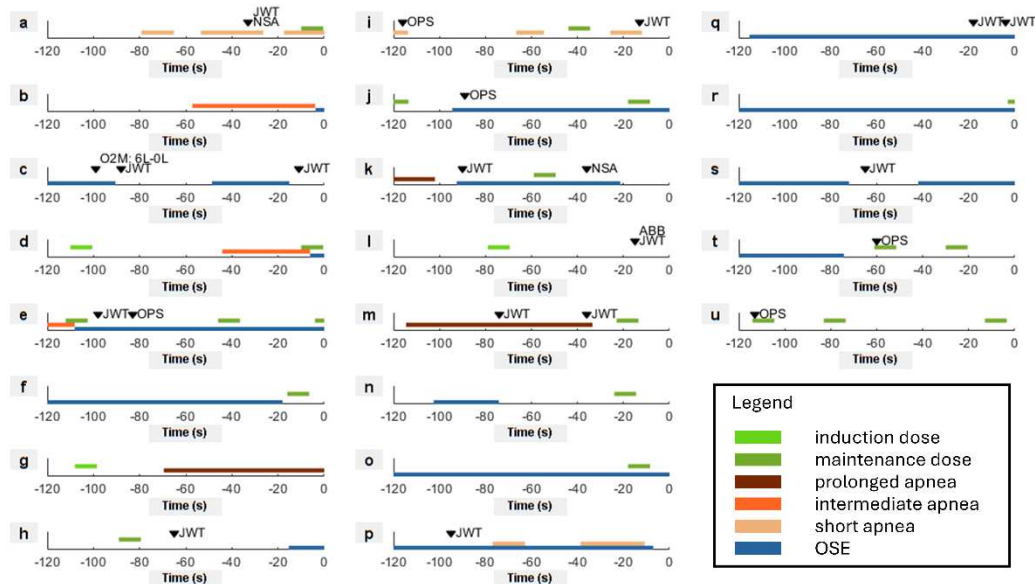


Figure 3. Event sequence graph showing the temporal association between sedative bolus injection, apnea, OSE, and subtle OD in 21 instances. The x-axis is in seconds; time 0 is the onset of subtle OD. OPS, start of procedure; NSA, nasal airway; JWT, jaw thrust/chin lift/head tilt; O2M, supplemental oxygen adjustment; ABB, manual ventilation. "O2M: 6L → 0L" in instance c indicates a change from 6 L · min⁻¹ to 0 L · min⁻¹; the O2M in instance c occurred after the end of the procedure. The OSE and apnea overlap in instance p because two snoring events spanned the apnea, with both belonging to the same OSE according to the definition. Bolus injections are plotted with a 10-s duration.

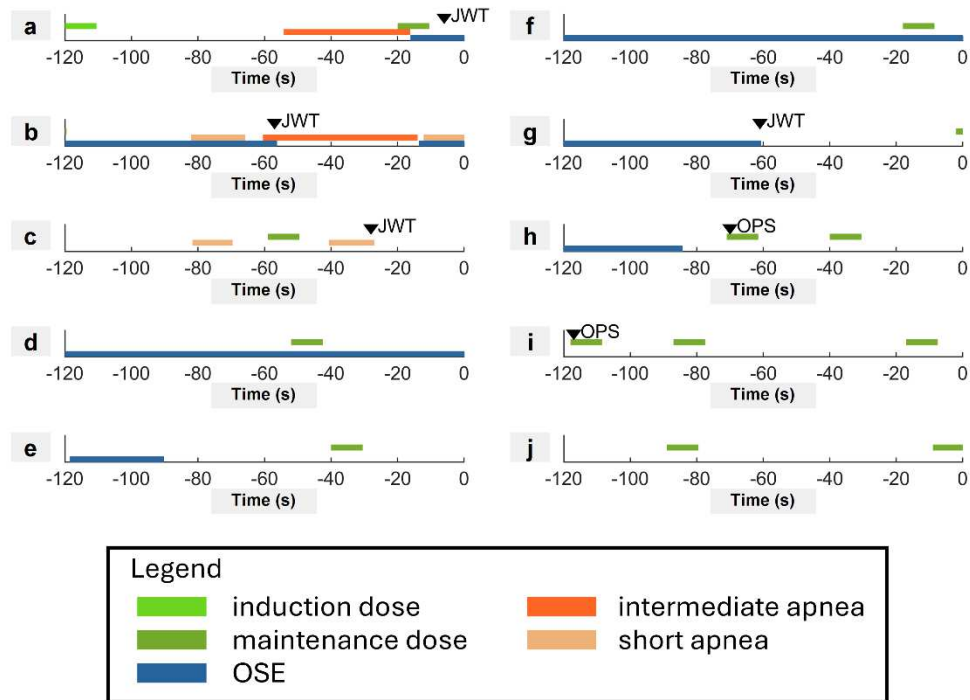


Figure 4. Event sequence graphs showing the temporal association between sedative bolus injection, apnea, OSE, and mild short OD. The x-axis is in seconds; time 0 is the onset of mild short OD. OPS, start of procedure; NSA, nasal airway; JWT, jaw thrust/chin lift/head tilt. OSE and apnea overlap in instance 2 because two snoring events spanned the apnea, with both belonging to the same OSE according to the definition. Bolus injections are plotted with a 10-s duration.

Figure 5 displays Venn diagrams showing the associations among sedative bolus injection, apnea, and partial airway obstruction before subtle OD (Figure 5a, b) and mild short OD (Figure 5c, d).

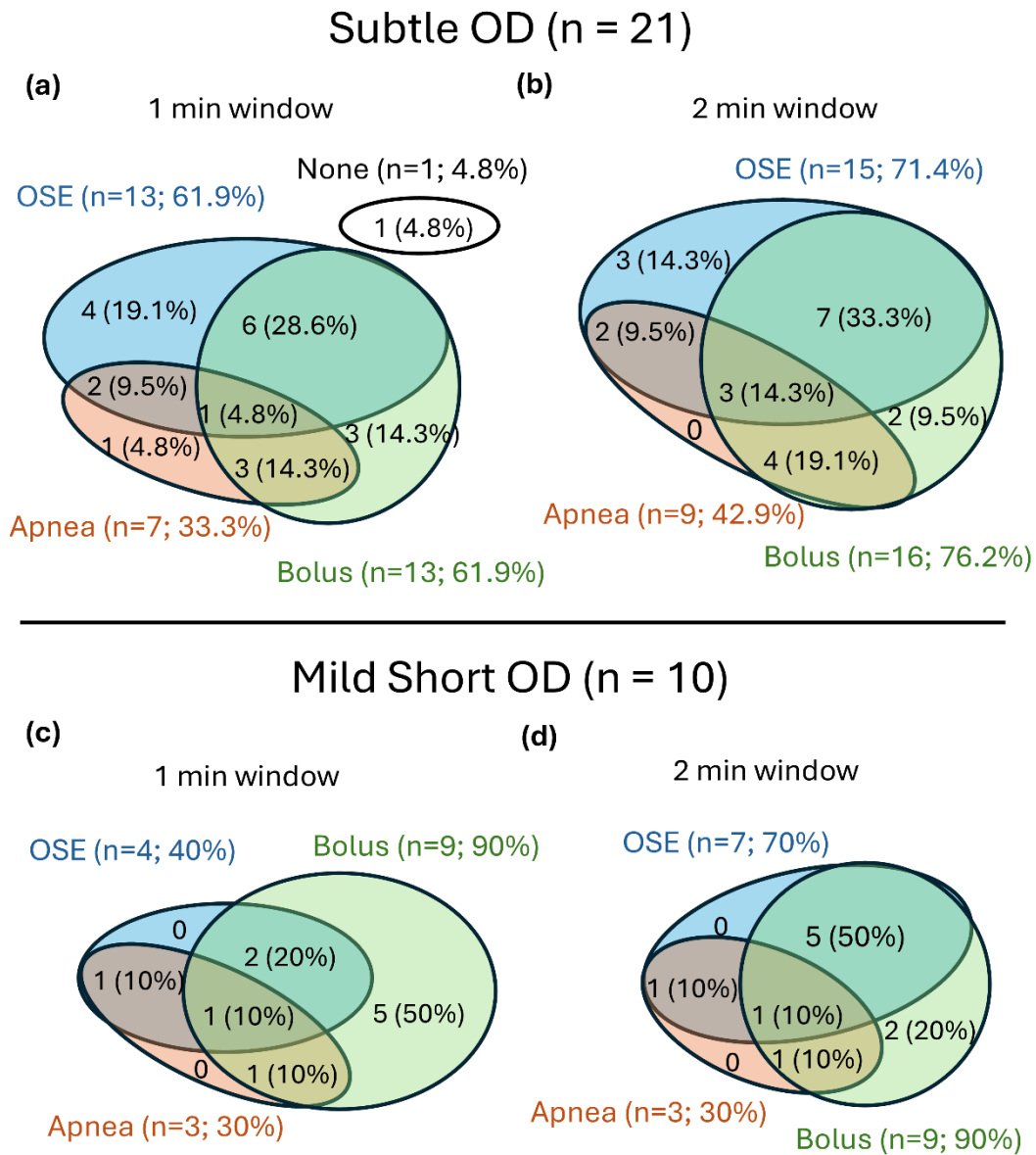


Figure 5. Venn diagrams illustrating the joint occurrence of sedative bolus injection, apnea, and OSE within 1- and 2-minute search windows preceding subtle OD and mild short OD: (a) 1-minute window of subtle OD, (b) 2-minute window of subtle OD, (c) 1-minute window of mild short OD, and (d) 2-minute window of mild short OD.

Across both OD types, apnea rarely occurred in isolation and most often co-occurred with OSEs and/or sedative bolus injection.

Table 4 presents the performance of the OSE detection algorithm across thresholds ranging from 0.05 to 0.95. The best F1 score of 0.754 was achieved at a threshold of 0.80; at the same threshold, the SEN was 0.704, and the PPV was 0.813.

Figure 6 shows SpO₂ (Figure 6a), EtCO₂ (Figure 6b), the tracheal sound spectrogram (Figure 6c), and the AI-detected OSE (Figure 6d) over a 90-second timeframe (from 5 min 38s to 7 min 08 s) in a mild short OD instance corresponding to Figure 4d, which was also a subtle OD case displayed in Figure 3j.

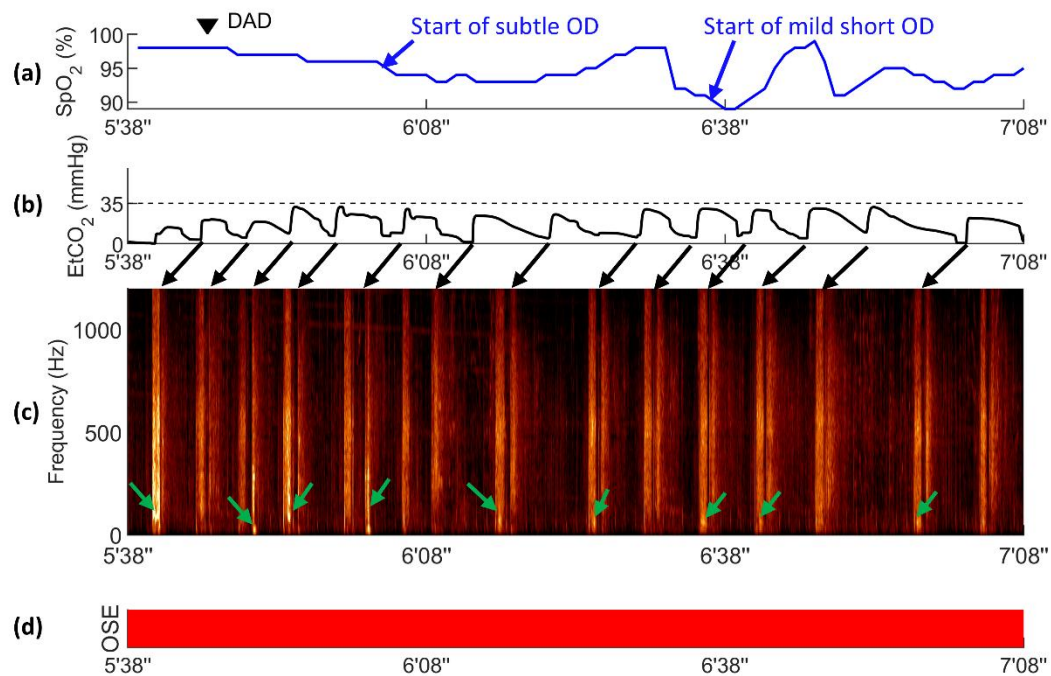


Figure 6. A 90-second timeframe showing the detection of an OSE before subtle OD and mild short OD. (a) SpO₂ trend (blue curve); (b) EtCO₂ trend (black curve); (c) tracheal sound spectrogram; and (d) AI-detected OSE label (red shading). The blue arrow indicates the onset of subtle OD and mild short OD. Black arrows connect EtCO₂ upstrokes to the corresponding exhalations (note: EtCO₂ lags actual expiratory sound by 5–10 s in this case). Green arrows indicate obstruction sound patterns. The red shading covers the entire displayed timeframe because obstruction sounds were also present in the preceding and subsequent periods. DAD, administration of the maintenance dose of sedatives.

The partial airway obstruction began well before the displayed timeframe, persisted for the displayed 90 seconds, and extended into the subsequent period. Partial airway obstruction caused obstruction sounds (green arrows in Figure 6c), which our proposed algorithm successfully identified as an OSE (red shading in Figure 6d).

Discussion

Hysteroscopy under procedural sedation in an outpatient setting has been shown to be safe, with low pain scores and a high degree of patient satisfaction [27]. In our study of 92 subjects, 277 OSEs and 337 total apneas (218 short, 88 intermediate, and 31 prolonged) occurred (Table 2). However, the number of OD events was relatively

low: only 21 subtle ODs and 10 mild short ODs occurred, with no mild long OD or severe OD observed (Table 2). This low incidence and low severity of OD, despite the high frequency of apneas and partial airway obstruction, support the safety of procedural sedation under standard clinical care.

Sedative bolus injections were frequently observed within the 1- and 2-minute windows preceding both subtle and mild short OD events (62–76% and 90%, respectively; Table 3), supporting a temporal association between sedative administration and respiratory compromise. Nevertheless, several OD events occurred without a recent bolus injection (24–38% of subtle OD and 10% of mild short OD events; Table 3), suggesting that clinicians should remain alert not only to immediate AREs after sedative administration but also to sustained or delayed respiratory events throughout the procedure.

As shown in the sequence graphs (Figures 3–4) and summarized in Table 3, OSEs were numerically more frequent than apnea within the 1- and 2-minute windows preceding OD (e.g., 62–71% vs. 33–43% before subtle OD, and 40–70% vs. 30% before mild short OD); this pattern persisted despite the overall dataset containing more apneas than OSEs (337 vs. 277 events; Table 2). Note that several OD events were preceded by OSEs without concurrent apnea (47.6% of subtle OD events in both windows; 20% and 50% of mild short OD events in the 1- and 2-minute windows,

respectively; Figure 5), whereas apnea occurred without a concurrent OSE in only 4 (19.1%) and 1 (10%) cases in each window for the subtle OD and mild short OD, respectively. Although the comparison between OSE and apnea frequencies did not reach statistical significance, likely owing to the limited number of observed OD events, these findings suggest that partial airway obstruction may be an important contributor to impaired ventilation during procedural sedation.

Table 4 lists the performance of the proposed OSE detection algorithm. Using the F1 score to determine the optimal threshold, the best threshold was 0.80, at which the F1 score was 0.754 (95% CI, 0.697 to 0.807), sensitivity was 0.704 (95% CI, 0.635 to 0.773), and PPV was 0.813 (95% CI, 0.749 to 0.871). The performance is acceptable but remains suboptimal, likely due to the model's inability to distinguish between actual obstruction sounds and vocal cord vibrations. When patients spoke or vocalized subconsciously, the model often misclassified these vocalizations as obstructions, thereby reducing overall performance. Future work could integrate a voice activity detection model to differentiate pathological obstruction from conversational speech or unconscious vocalizations. Nonetheless, the proposed model represents an important first step toward a trustworthy digital tracheal auscultation system for monitoring partial airway obstruction during procedural sedation.

Limitations

This study has several limitations. First, the study covered only the procedure stage and excluded the post-anesthesia recovery stage. This is because subjects in the PACU often mumbled unconsciously and moved, which led to (1) difficulty in establishing ground-truth labels, (2) an increase in false-positive predictions by the deep learning model, and (3) fluctuation in SpO₂ measurements due to imperfect sensor-to-skin contact. Furthermore, peripheral vasoconstriction induced by low ambient temperature compromised the accuracy of pulse oximetry data in the PACU. Second, we were unable to identify hypopnea (slow or shallow breathing), which also contributes to OD. Notably, 19.0% and 9.5% of subtle OD events, and 50% and 20% of mild short OD events, within the 1- and 2-minute windows, respectively, were preceded by neither an OSE nor an apnea (Figure 5), suggesting that undetected hypopnea may account for a substantial proportion of these events. Developing criteria for identifying hypopnea based on acoustic analysis warrants further study. Third, the data were all obtained from female subjects undergoing hysteroscopy under procedural sedation at a single center. The dataset lacked diversity, and the AI model's generalizability was not tested.

Conclusion

Partial airway obstruction was frequently observed before OD during procedural sedation, often without concurrent apnea. Sustained obstruction may also occur beyond the immediate post-bolus period. These findings suggest that clinicians should monitor both apnea and partial airway obstruction during procedural sedation. The proposed AI model may support automated monitoring of partial airway obstruction and could be integrated with apnea detection to enhance respiratory safety.

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All authors approved the final version for publication and agree to be accountable for all aspects of the work.

Data Availability Statement

The de-identified data and analysis code that support the findings of this study are available from the corresponding author upon reasonable request, subject to institutional and ethical approval.

Conflict of Interest

The AS-101 acoustic sensor and Airmod device evaluated in this study are products of Heroic Faith International Ltd. Heroic Faith Medical Science Co., Ltd. provided the AI model, ground-truth labels, and technical support. The authors declare no personal financial conflicts of interest related to this work.

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Tables

Table 1. Demographic and clinical characteristics of subjects.

Characteristics	Mean (SD) or n (%) (N = 92)
Age (years)	43.3 (10.5)
Height (cm)	160.9 (5.2)
Weight (kg)	59.7 (10.5)
BMI (kg · m ⁻²)	23.1 (4.1)
Neck circumference (cm)	32.9 (2.7)
ASA Score	
I	0 (0%)
II	89 (97%)
III	3 (3%)
Charlson Comorbidity Index	
0	64 (70%)
1	21 (23%)
2	4 (4%)
3	3 (3%)
≥ 4	0 (0%)
Sedative delivery approach	
Bolus	89 (97%)
Continuous (TCI)	3 (3%)

ASA, American Society of Anesthesiologists; BMI, body mass index; SD, standard deviation; TCI, target-controlled infusion.

Table 2. Number of incidents of adverse respiratory events, sedative bolus injection, and airway management.

Events	Total number of events	Subjects involved, n (%) (N = 92)
Sedative bolus injection	454	92 (100%)
OSE	277	80 (87%)
Oxygen desaturation		
Subtle OD ^a	21	15 (16%)
Mild short OD ^a	10	8 (9%)
Mild long OD	0	0 (0%)
Severe OD	0	0 (0%)
Apnea		
All apnea	337	83 (90%)
Short apnea (10–30 s) ^b	218	70 (76%)
Intermediate apnea (30–60 s) ^b	88	51 (55%)
Prolonged apnea (≥ 60 s) ^b	31	26 (28%)
Airway management		
Nasal airway ^c	15 ^d	12 (13%)
Oral airway	0	0 (0%)
Laryngeal mask airway	0	0 (0%)
Endotracheal airway	0	0 (0%)
Airway positioning maneuver ^e	434	89 (97%)
Manual ventilation ^f	92	37 (40%)

OSE, obstruction sound episode. OD, oxygen desaturation. ^a Subtle OD and mild short OD were not mutually exclusive. ^b Short, intermediate, and prolonged apnea were mutually exclusive. ^c Including insertion and repositioning. ^d Including insertion and repositioning of the nasal airway. ^e Including jaw thrust, chin lift, and head tilt. ^f Using a reservoir bag on the breathing system of the anesthesia machine.

Table 3. Number of instances with at least one sedative bolus injection, apnea, or OSE in the 1- or 2-minute window preceding subtle OD and mild short OD.

Event	Subtle OD (n = 21)		Mild short OD (n = 10)	
	1-min window	2-min window	1-min window	2-min window
Sedative bolus injection	13 (62%)	16 (76%)	9 (90%)	9 (90%)
OSE	13 (62%)	15 (71%)	4 (40%)	7 (70%)
Apnea	7 (33%)	9 (43%)	3 (30%)	3 (30%)

OSE, obstruction sound episode. OD, oxygen desaturation.

Table 4. Performance of the OSE detection algorithm across thresholds. Bold values indicate the best F1 score.

Threshold	Sensitivity, Mean (95% CI)	PPV, Mean (95% CI)	F1 score, Mean (95% CI)
0.05	0.372 (0.297 to 0.451)	0.446 (0.363 to 0.533)	0.406 (0.338 to 0.478)
0.10	0.473 (0.380 to 0.564)	0.516 (0.435 to 0.598)	0.493 (0.417 to 0.563)
0.15	0.531 (0.435 to 0.637)	0.568 (0.490 to 0.641)	0.549 (0.471 to 0.625)
0.20	0.570 (0.470 to 0.656)	0.610 (0.541 to 0.682)	0.590 (0.515 to 0.656)
0.25	0.581 (0.490 to 0.671)	0.624 (0.551 to 0.691)	0.602 (0.527 to 0.668)
0.30	0.574 (0.493 to 0.665)	0.616 (0.540 to 0.689)	0.594 (0.526 to 0.668)
0.35	0.628 (0.546 to 0.715)	0.628 (0.563 to 0.702)	0.628 (0.564 to 0.696)
0.40	0.650 (0.561 to 0.732)	0.667 (0.596 to 0.735)	0.658 (0.590 to 0.720)
0.45	0.650 (0.564 to 0.736)	0.677 (0.604 to 0.749)	0.663 (0.591 to 0.733)
0.50	0.643 (0.558 to 0.725)	0.687 (0.615 to 0.756)	0.664 (0.594 to 0.731)
0.55	0.657 (0.575 to 0.739)	0.703 (0.630 to 0.771)	0.679 (0.607 to 0.746)
0.60	0.671 (0.595 to 0.755)	0.713 (0.645 to 0.771)	0.691 (0.625 to 0.757)
0.65	0.697 (0.624 to 0.772)	0.739 (0.674 to 0.800)	0.717 (0.656 to 0.775)
0.70	0.708 (0.640 to 0.784)	0.760 (0.701 to 0.814)	0.733 (0.679 to 0.793)
0.75	0.704 (0.632 to 0.776)	0.783 (0.726 to 0.842)	0.741 (0.683 to 0.798)
0.80	0.704 (0.635 to 0.773)	0.813 (0.749 to 0.871)	0.754 (0.697 to 0.807)
0.85	0.686 (0.616 to 0.751)	0.826 (0.758 to 0.884)	0.750 (0.690 to 0.802)
0.90	0.653 (0.585 to 0.720)	0.858 (0.786 to 0.923)	0.742 (0.680 to 0.798)
0.95	0.505 (0.425 to 0.581)	0.875 (0.805 to 0.939)	0.641 (0.566 to 0.704)

CI, confidence interval; PPV, positive predictive value. Bootstrapped 95% CIs were based on 1,000 participant-level resamples.

Supplementary Files

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