ORIGINAL

Usefulness of new acoustic respiratory sound monitoring with artificial intelligence for upper airway assessment in obese patients during monitored anesthesia care

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Abstract : Monitored anesthesia care (MAC) often causes airway complications, particularly posing an elevated risk of aspiration and airway obstruction in obese patients. This study aimed to quantify the levels of aspiration and airway obstruction using an artificial intelligence (AI)-based acoustic analysis algorithm, assessing its utility in identifying airway complications in obese patients. To verify the correlation between the stridor quantitative value (STQV) calculated by acoustic analysis and body weight, and to further evaluate fluid retention and airway obstruction, STQV calculated exhaled breath sounds collected at the neck region, was compared before and after injection of 3 ml of water in the oral cavity and at the start and end of the MAC procedures. STQV measured immediately following the initiation of MAC exhibited a weak correlation with body mass index. Furhtermore, STQV values before and after water injection increased predominantly after injection, further increased at the end of MAC. AI-based analysis of cervical respiratory sounds can enhance the safety of airway management during MAC by quantifying airway obstruction and fluid retention in obese patients. J. Med. Invest. 70 : 430-435, August, 2023

INTRODUCTION

In Monitored Anesthesia Care (MAC) for procedures such as gastrointestinal endoscopy and dental treatments, ventilation issues often occur due to upper airway obstruction caused by the overlap between the airway and the operative field, and obesity or overweight with a narrow airway space is a major relevant risk factor. Upper airway obstruction occurs intermittently during MAC because of the effects of treatment procedures ; however, oxygen administration through a nasal cannula or high-flow causes a slow decline in oxygen saturation, delaying arterial oxygen saturation (SpO₂) monitoring to detect upper airway obstruction (1). Moreover, when a capnogram sampling tube for respiratory monitoring is inserted into the nose, respiratory detection becomes impossible during mouth breathing. However, many studies on sleep or airway management have reported that the sinking of the tongue's base occurs due to a decrease in consciousness levels in many obese patients, making them unable to breathe nasally (2, 3). It is important to recognize partial upper airway obstruction and implement measures such as adjusting the chin position and reducing the dosage of sedatives to prevent a transition to mouth breathing.

The acoustic respiratory rate (RRa) monitoring device (Masimo Corp., Irvine, CA, USA), which is currently available for sale, can measure the respiratory rate using the magnitude of respiratory sounds (4, 5). Upper airway obstruction can be identified by listening to snoring or wheezing sounds ; however, this requires subjective evaluation and expertise. In contrast, artificial intelligence (AI) acoustic analysis is a technique that quantifies abnormal respiratory sounds and that anyone can use instantly to diagnose airway obstruction (6, 7).

This study aimed to capture the early signs of airway complications using machine learning technology. AI analysis has been gradually introduced in various medical fields in recent years, including radiological diagnosis, endoscopy, and histopathological diagnosis (8). Machine learning technology is also gradually being applied in breath sound analysis (9-11). Our research group has developed an AI-based algorithm to quantify fine and coarse crackles, wheezes, and similar snoring sounds using an AI machine learning-based breath sound analyzer (6, 7).

This developed AI analysis algorithm can instantly identify changes in the frequency of sounds due to airflow restriction (partial obstruction) during upper airway obstruction. Furthermore, for verification, this machine-learning algorithm includes changes in the sound elements of inspiratory flow generated by the retention of fluid, including saliva, in the upper airway. We

aimed to investigate the feasibility of detecting respiratory adverse events using an AI-based acoustic monitoring algorithm.

PATIENTS AND METHODS

This prospective cohort study was designed and conducted in accordance with the Declaration of Helsinki and its guidelines. This study was approved by the Hiroshima Certified Review Board (approval number : CRB2022-0002), and written informed consent was obtained from all subjects participating in the trial. The trial was registered prior to patient enrollment at the Japan Registry of clinical trials (jRCTs062220054).

Study design

Participants who underwent dental treatment under MAC at the Hiroshima University Hospital between September and November 2022 were included. The inclusion criteria were an age ≥18 years, capability to undergo dental procedures on an outpatient basis, phobia of dental treatment, abnormal gag reflex, and ability to undergo invasive dental procedures. The exclusion criteria were allergy and history of serious adverse reactions to midazolam or propofol, dysphagia, poor oral hygiene, and mental disability.

In accordance with the Japanese guidelines for the management of obesity, patients with a body mass index (BMI) ≤ 25 kg/m² and > 25 kg/m² were assigned to the non-obese and obese groups, respectively (12).

Calculation of STQV

The AI analysis algorithm for calculating the stridor quantitative value (STQV) included 56 labeled sounds comprising characteristic frequency bands/continuations as teacher data for machine learning. Specifically, feature parameters were extracted from the snoring caused by upper airway obstruction due to the base of the tongue falling back and from the stridor sounds generated by the resonance of water-soluble reservoirs between inspiration and expiration using frequency analysis, cepstrum analysis, liftering process, and other methods. Subsequently, coefficients of the feature parameters were derived using AdaBoost as a machine learning algorithm and by inputting 56 pieces of labeled teacher data (Figure. 1).
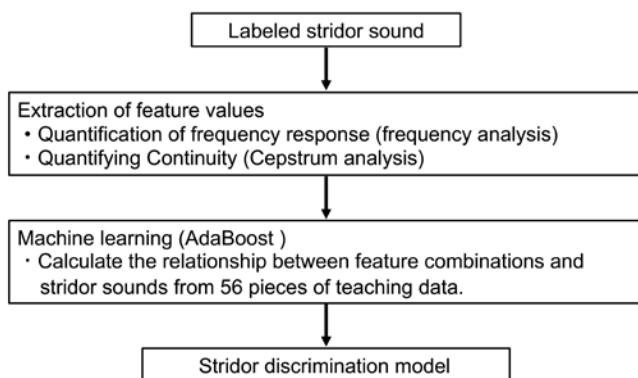
Study protocol

A bedside monitor, CARESCAPE™ B850 (GE Healthcare, Chicago, IL, USA), was used to measure blood pressure and SpO_2 and obtain an electrocardiogram and capnogram. Subsequently, the venous route was secured, and propofol (10 or 20 mg bolus, followed by 0.8–4 mg/kg/h as continuous dosage) and midazolam (1–2.5 mg bolus) were administered. RRa sensor in Radical 7 (Masimo Corp., Irvine, CA, USA) was then attached with adhesive tape to the skin of the left paralarynx and sensor of the continuous monitoring system for respiratory sounds to the skin of the right paralarynx (Figure 2). Sedation levels were managed in the range of 3–4 on the Observer's Assessment of Alertness/Sedation (OAA/S) scale. All patients received oxygen at 3 L/min through a nasal cannula. Cervical respiratory sounds were recorded after sedation was induced, and 3 ml of water was thereafter injected intraorally with a syringe. Cervical respiratory sounds were recorded, and dental treatment was subsequently initiated. During dental treatment, cervical respiratory sounds were recorded at the onset of coughing (choking), at the detection of apnea for 20 s each using a capnogram and RRa, and at the end of MAC. Dental treatment was interrupted for cervical inspiratory sound recording (STQV analysis in a quiet environment) only the first time each event occurred (Figure 3).

Statistical analysis and sample size calculation

The sample size estimation in this study was based on a previous interstitial lung disease detection power analysis using fine crackle sound AI analysis published by this study's research group (7), which showed that the fine crackle sound AI index was 0.032 ± 0.023 in the control group and 0.121 ± 0.090 in the interstitial lung disease group. From these values, the effect size was

Figure 1.   Machine learning algorithms for the values of the stridor component. Based on a training dataset of stridor sounds recorded from patients and labeled by experts, features were extracted using frequency, local variance, and cepstrum analyses, and machine learning algorithms were applied.

Figure 2.   Photograph of the nasal cannula for oxygen administration. Nasal capnogram sampling tube, a sensor for continuous monitoring system for respiratory sounds device, and a sensor of acoustic respiration rate when fitted are shown.
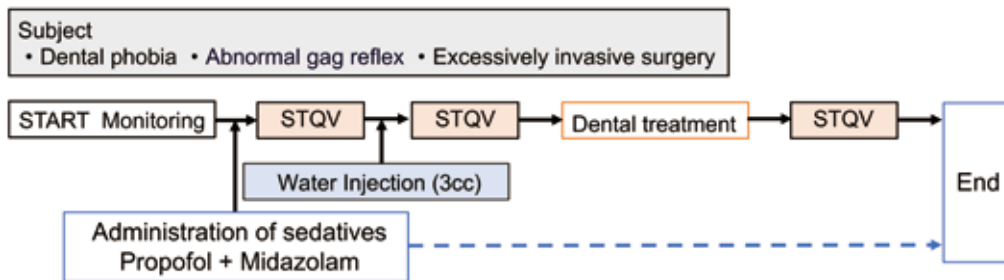
Figure 3. Schematic diagram of the study protocol. Cervical intake sounds were recorded in the boxes painted in orange, and a post-analysis of the values of the stridor component was performed. RRa, acoustic respiratory rate.

calculated to be 0.94 using the software G*Power version 3.1.9.6. The final target sample size was estimated to be nine subjects using an alpha level of 0.05 and power of 0.8.

Student's t-test was used to compare continuous variables between two groups, whereas the one-way analysis of variance was used to compare multiple groups, and Pearson's correlation coefficient was used for bivariate analysis. All analyses were performed using SPSS version 25 for Mac (IBM Corp. ; Armonk, NY, USA). A P-value <0.05 was considered statistically significant.

RESULTS

The study flowchart is shown in Figure 4. Sixty-seven patients who underwent dental treatment under MAC at the Hiroshima University Hospital between September 22 and November 14, 2022 were included. Of these patients, five who did not give consent and two whose anesthesiologist made an error in the study procedure were excluded.

Participants' baseline characteristics, including age, height, weight, BMI, and male-to-female ratio, are presented in Table 1. Regarding the implementation status of MAC, the average amounts of propofol and midazolam administered and average anesthesia time are also presented in Table 1. The STQV measured immediately after the start of MAC showed a weak correlation with BMI (R = 0.35, P = 0.006), and when the BMI was classified into four categories and compared using an analysis of variance, the STQV values significantly increased with BMI (P = 0.046) (Figure 5).

To confirm the feasibility of detecting respiratory adverse events using STQV, the STQV before and after injecting 3 ml of

water into the mouth of obese patients with a BMI of ≥25 kg/m² were compared. STQV values before and after injection were 0.0679 ± 0.056 and 0.1415 ± 0.111, respectively (P < 0.007 ; 95% confidence interval [CI], -0.125 to -0.0225), indicating a significant increase in STQV after water injection into the mouth (Figure 6).

Furthermore, STQV values at the start and end of IVS were compared to investigate the feasibility of using STQV to detect upper airway changes caused by anesthetic accumulation. The STQV value at the start and end of MAC were 0.0679 ± 0.056 and 0.173 ± 0.129, respectively (P < 0.007, 95% [CI] -0.172 to -0.0392). It was confirmed that STQV could help detect upper airway narrowing caused by sedation levels (Figure 7).

Table 1. Participants' background and anesthesia dosage

Age (years)	47.9 ± 15 [20−84]
Sex (female / male)	35/25
Height (cm)	161 ± 9.5 [140−183]
Weight (kg)	60.6 ± 16.3 [38−118]
BMI (kg/m²)	23.3 ± 5.4 [14.3−40.8]
Drug (dosage)	
Propofol (mg)	100.2 ± 43.6 [37.4−239.7]
Midazolam (mg)	2.2 ± 0.6 [1−5]
Anesthesia time (min)	50.4 ± 16.5 [21−97]

Values are presented as mean ± standard deviation [min-max] or number (proportion). BMI, body mass index.
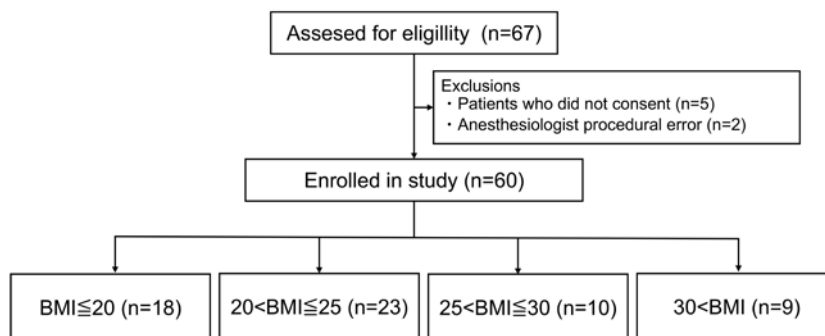

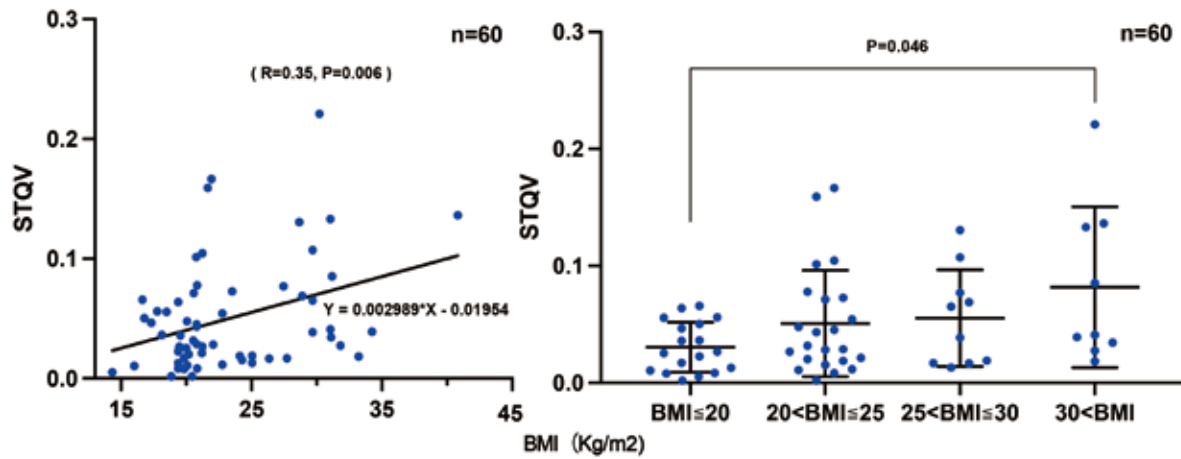**Figure 4.** Schematic diagram of the study. BMI, body mass index.

Figure 5.   Left figure ; scatter plots and regression lines of BMI and STQV immediately following the initiation of MAC. BMI and STQV were weakly correlated (R = 0.35, P = 0.006). Right figure : BMI was classified into four categories (BMI ≤20 [n = 18], 20<BMI≤25 [n = 23], 25≤BMI<30 [n = 10], and BMI ≥30 kg/m² [n = 9]) and compared using an analysis of variance. STQV value significantly increased with BMI (P = 0.046). The horizontal line indicates the mean deviation. Statistical analyses were performed using a one-way Analysis of Variance. BMI, body mass index ; STQV, quantitative values of the stridor component.
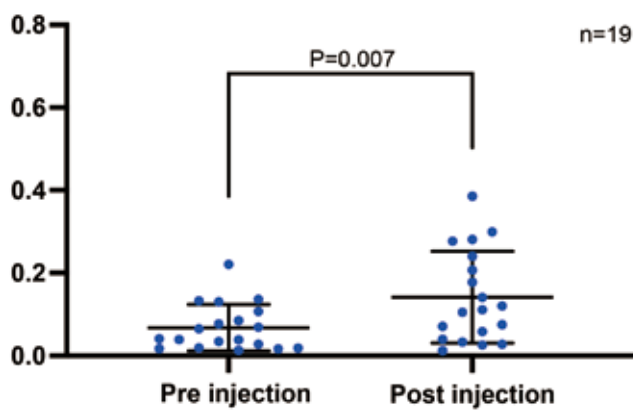

Figure 6.   Comparison of STQV before and after water injection into the mouth of obese patients. The STQV values pre- and post-injection were 0.0679 ± 0.056 and 0.1415 ± 0.111, respectively (P<0.007, 95% confidence interval [CI] -0.125 to -0.0225), indicating a significant increase in STQV following water injection into the mouth. The horizontal line indicates the mean deviation. Statistical analysis were performed using a student's t-test. BMI, body mass index ; STQV, quantitative values of the stridor component.
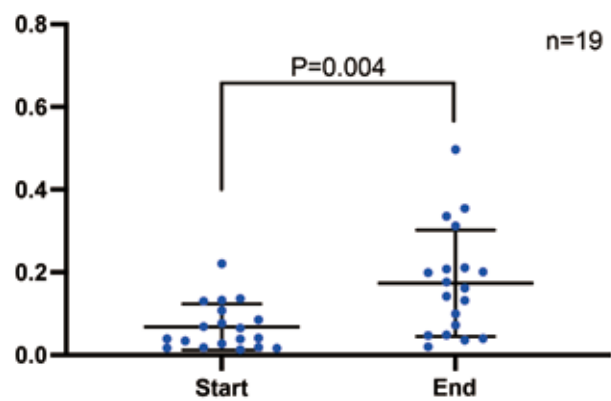

Figure 7.   Comparison of STQV at the start and end of MAC in obese patients. The STQV value at the start and end of MAC were 0.0679 ± 0.056 and 0.173 ± 0.129, respectively (P<0.007, 95% [CI] -0.172 to -0.0392), confirming that STQV can help detect upper airway narrowing caused by sedation levels. The horizontal lines represent mean deviations. Statistical analysis was performed using a student's t-test. BMI, body mass index ; MAC, monitored anesthesia care; STQV, quantitative values of the stridor component.

DISCUSSION

This study developed the STQV index for analyzing respiratory sounds in the neck using AI technology to quantify adverse sounds in the respiratory system. The effectiveness of this system in evaluating airway function in obese patients under IVS was examined. Results showed that STQV immediately after IVS correlated with BMI and that airway narrowing due to obesity could be quantified using STQV.

Sedative drugs, including midazolam, can cause upper airway collapse and increase airway resistance, and a significant increase in nasal resistance leads to mouth breathing, making it impossible for capnogram to detect exhalation (13). STQV quantifies airway patency, and adding it to airway assessment during IVS suggests its usefulness in assessing the necessity,

including lifting the chin, extending the neck, and elevating the body (14-16).

Furthermore, propofol and midazolam suppress swallowing function and endoscopic instruments, including mouth openers, make swallowing difficult, leading to the retention of fluid, such as saliva, in the upper airway, which increases the risk of aspiration (17).

Therefore, a comparison of STQV before and after oral water injection was conducted, confirming an increase in STQV following water injection, thereby demonstrating the feasibility of using STQV to quantify upper airway fluid retention.

Gemma *et al*. reported that sedation using propofol, in particular, suppresses swallowing function, causing fluid retention in the pharynx and increasing the risk of aspiration (18). The anesthesiologists must manage fluid retention in the pharyngeal

region by suctioning, adjusting the head and body position, and adjusting the sedation levels for procedures involving intraoral water injection and bleeding ; however, it is difficult to detect fluid retention using the existing monitoring systems, and STQV may be an important indicator to monitor.

MAC is performed in the supine position with the mouth open, which increases upper airway collapse during treatment and examination (16). These limitations are considered risk factors for apnea owing to airway obstruction and choking during non-intubated MAC (19). Particularly, the risk is high in obese patients ; therefore, monitoring devices that can diagnose the level of airway patency in real-time accurately are important.

Investigations pertaining to airway patency in obese patients encompass numerous reports, including assessments of airway conditions during sleep and airway management under sedation (2, 11). These studies have measured and validated airway velocity and critical pharyngeal pressure ; however, these measurements require the insertion of sensors, making monitoring invasive (20, 21). In contrast, our respiratory sound monitoring system employs a hermetically sealed, noise-cancelling stick-type sensor, allowing for non-invasive and convenient visualization of the STQV (22). This suggests the potential utility of STQV in airway assessment for MAC.

STQV levels increased after an intraoral injection and remained similarly elevated at the end of the MAC period compared with the start. The present study's results showed the same trend in obese and non-obese patients. Considering these results, the application of STQV monitoring during MAC may not be limited to obese patients. In addition, we aim to further investigate the clinical usefulness of STQV monitoring by validating it in morbidly obese patients (BMI > 35 kg/m²), a high-risk group for anesthetic-induced airway obstruction.

This study had several limitations. First, the treatment criteria (type of sedative, dosage, and level of sedation) for sedation management in this study were not clearly defined in advance and were left to each physician's discretion. Second, the neck inspiratory volume values calculated in this study were absolute and not calibrated for each patient. Therefore, the basic volume picked by the sensor may differ among patients. However, objective monitoring of cervical inspiratory volume using the proposed system may enhance the safety of patients under MAC. Third, the correlation between STQV and BMI was weak, possibly due to the high false negative rate. In the future, there is a need to improve specificity by optimizing the validation data set and improving sensor performance. Finally, this study covered procedures were limited to dental care, which may not represent a typical patient receiving MAC. To eliminate this possibility, the evaluation of STQV was performed evaluated during dental treatment interruption in a noise-free quiet environment.

CONCLUSION

A significant correlation was observed between BMI and STQV, which promptly responded to airway obstruction and upper airway fluid retention caused by MAC. These results suggest the potential of STQV in rapidly diagnosing airway adverse events during MAC, which are frequent in obese patients.

ACKNOWLEDGMENTS

STATEMENT OF ETHICS

This study was approved by the Hiroshima Certified Review Board (approval number : CRB2022-0002). Written informed consent was obtained from all subjects participating in the trial. The trial was registered prior to patient enrollment at the Japan Registry of clinical trials (jRCTs062220054).

CONFLICT OF INTEREST STATEMENT

The authors declare that they have no competing interests.

FUNDING SOURCES

AUTHOR CONTRIBUTIONS

YS made a study design, collected the data, and drafted the paper. NS made a study design and discussed the results. MD, KO, MY, TT and AO collected the data and discussed the results. SO and TS advised the study design and discussed the results. YM T and NS supervised the study, analyzed the data, and revised the paper. The authors read and approved the final manuscript.

DATA AVAILABILITY STATEMENT

The data supporting this study's findings are available from the corresponding author upon reasonable request.

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