Heliyon 10 (2024) e35053

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Research article

Unveiling the impact of airways: A comparative analysis of oropharyngeal and nasopharyngeal airways in painless fiberoptic bronchoscopy

Pei Zhou [a,b], Di Fu [c], Cong Luo [a,b], Ru-Ping Dai [a,b], Ru-Yi Luo [a,b,*]

[a] Department of Anesthesiology, The Second Xiangya Hospital, Central South University, Changsha, China
[b] Anesthesia Medical Research Center, Central South University, Changsha, China
[c] Department of Anesthesiology, Xiangya Hospital, Central South University, Changsha, China

ARTICLE INFO

Keywords:
Hypoxemia
Nasopharyngeal airway
Oropharyngeal airway
Painless fiberoptic bronchoscopy
Remimazolam besylate
Oxygen saturation

ABSTRACT

Background: This study compared the efficacy of oropharyngeal airways (OA) and nasopharyngeal airways (NA) in maintaining oxygenation during painless fiberoptic bronchoscopy (PFB) in patients sedated with remimazolam besylate.

Methods: Two hundred and fifty-two patients were randomized to the OA or NA group. Remimazolam besylate was used for anesthesia induction and maintenance in both groups. We measured and recorded several physiological parameters, including mean arterial pressure, heart rate and oxygen saturation (SpO2), at various time points: before anesthesia (T1), after anesthesia induction (T2), immediately after the bronchoscope reached the trachea (T3), during the procedure (T4), and 5 min after transfer to the post-anesthesia care unit (T5). The incidence and frequency of hypoxemia, minimum SpO2 during the procedure and patient awakening time after flumazenil administration were also recorded. Additionally, the relationship between minimum SpO2 and body mass index (BMI) was investigated.

Results: Patients in the NA group experienced a higher incidence of hypoxemia compared to the OA group. Patients in the OA group maintained higher SpO2 levels at T3 and had a higher minimum SpO2 during the procedure than the NA group. Furthermore, a significant negative correlation was observed between minimum SpO2 and BMI. Following flumazenil anesthesia reversal, nearly 97 % of patients awakened within 1 min.

Conclusions: This study suggests that OA may provide a better safety profile than NA by preserving respiratory function during PFB.

1. Introduction

In recent years, fiberoptic bronchoscopy has been widely used to diagnose and treat respiratory diseases [1,2]. According to the British Thoracic Society guidelines for flexible bronchoscopy in adults, patients undergoing bronchoscopy should be offered intravenous sedation as long as there are no contraindications [3]. Fiberoptic bronchoscopy can be performed under various anesthesia techniques, including general anesthesia with tracheal intubation or laryngeal mask airway, intravenous sedation and topical

* Corresponding author. Department of Anesthesiology, The Second Xiangya Hospital, Central South University, Central Ren-Min Road No. 139, Changsha, 410011, Hunan Province, China.
E-mail address: luoruyi@csu.edu.cn (R.-Y. Luo).

https://doi.org/10.1016/j.heliyon.2024.e35053
Received 14 May 2024; Received in revised form 5 July 2024; Accepted 22 July 2024
Available online 23 July 2024

anesthesia. Painless fiberoptic bronchoscopy (PFB) involves the administration of sedative and analgesic medications to achieve a state of minimal sedation during the procedure. This allows for a brief period of amnesia and reduced discomfort, enabling the patient to tolerate the procedure while awakening rapidly afterward with minimal recall of the experience [4]. PFB avoids the physiological and psychological discomfort caused to patients during routine bronchoscopy under local anesthesia, makes patients more comfortable, improves the positive sampling rate, shortens the examination time and reduces the re-examination rate [5]. PFB aims to ensure safety, comfort and prompt awakening, in line with the trend towards more comfortable medical care and improved postoperative recovery.

Maintaining normoxia is a critical aspect of the anesthesiologist's role during the procedure [6]. Using a laryngeal mask airway (LMA) during fiberoptic bronchoscopy can alleviate hypoxemia and facilitate easy access to the glottis, particularly in patients with subglottic obstruction and those at high risk [7]. However, the LMA is still considered an invasive form of ventilation and requires a certain depth of anesthesia. Due to the increasing demand for comfortable diagnosis and treatment, there is a pressing requirement for an increased availability of non-invasive and expeditious ventilation support tools. It is now understood that non-invasive ventilation tools such as oropharyngeal airways (OA) and nasopharyngeal airways (NA) can offer airway support. Previous studies have shown that OA are associated with several benefits. For example, one study found that OA were linked to a significantly lower incidence of hypoxia, shorter endoscopy entry time and more stable hemodynamics in elderly patients undergoing esophagogastroduodenoscopy [8]. Moreover, another study reported that using NA in obese patients during painless gastroscopy resulted in less SpO2 reduction than nasal oxygen tubes [9]. Furthermore, nasopharyngeal apnoeic oxygenation has been demonstrated to prolong safe apnea time and reduce the risk of desaturation in morbidly obese patients [10]. However, despite these findings, the use of OA and NA in PFB remains limited in terms of established application experience.

To address this knowledge gap, we conducted a prospective, randomized study comparing the efficacy and safety of NA and OA in patients undergoing PFB with intravenous anesthesia. The study specifically assessed the ability of both devices to maintain respiratory function and oxygenation while also monitoring for potential adverse events.

2. Materials and methods

Ethics approval

We conducted a prospective randomized controlled trial following approval from our institution's ethics committee (approval number: 20230326). Before patient enrollment, the trial was prospectively registered at the Chinese Clinical Trial Register (ChiCTR2400079589) (https://www.chictr.org.cn/bin/project/edit?pid=202069). Written informed consent was obtained from all patients before enrollment. The study was carried out between January 2024 and April 2024.

2.1. Study population

This study enrolled adult patients aged 18–85 years old, regardless of gender. To participate, patients needed an American Society of Anesthesiologists (ASA) Class I-III classification and a metabolic equivalent (MET) greater than 3. Exclusion criteria included: severely loose teeth, deviated nasal septum, history of nasal surgery, extremely severe obstructive ventilation dysfunction, pre-anesthesia oxygen saturation below 90 %, or existing respiratory failure. All enrolled patients met the necessary criteria for undergoing fiberoptic bronchoscopy.

2.2. Anesthesia protocol

Prior to the procedure, all patients were instructed to abstain from solid food for 8 h and clear liquids for 2 h. Upon arrival in the anesthesia preparation room, intravenous access was established. Standard monitoring equipment, including a pulse oximeter, three-lead ECG and non-invasive blood pressure cuff, were applied after entering the operating room. Patients received oxygen inhalation through a nasal cannula at a flow rate of 2 L/min. Lidocaine aerosol was administered three times to achieve topical pharyngeal anesthesia. Fiberoptic bronchoscopy was performed via the nasal route in all patients. Remimazolam besylate was injected intravenously for both induction using a micropump at a dose of 0.05–0.2 mg/kg and maintenance of anesthesia. Additional bolus doses of 1–2 mg of remimazolam besylate were administered as needed based on clinical judgment and the patient's response. Following the induction of anesthesia, patients were randomly assigned to either the OA group (n = 126) or the NA group (n = 126) using a random number table method. Finally, the appropriate airway device (OA or NA) was inserted.

If a patient's mean arterial pressure (MAP) decreased by more than 20 % from baseline, intravenous M-hydroxylamine (a vasopressor) was administered at a dose of 0.2–0.5 mg until MAP normalized. Topical pharyngeal anesthesia with 2 % lidocaine hydrochloride solution (5 ml) was administered as needed during the fiberoptic bronchoscopy procedure. Following the procedure, flumazenil (0.5 mg) was administered to reverse the effects of remimazolam besylate. All patients were monitored closely in the post-anesthesia care unit (PACU) for at least 30 min before discharge following fiberoptic bronchoscopy and recovery. The anesthesiologists involved in the study were highly experienced.

2.3. Management of SpO2 reduction

Prior to anesthesia induction, all patients received supplemental oxygen via a nasal cannula at a flow rate of 2 L/min. During anesthesia maintenance, oxygen administration was continued, either through the OA or NA, depending on the chosen airway device

and as long as the patient's SpO2 remained at or above 90 %. Hypoxemia, characterized by a SpO2 value below 90 % [11,12], is one of the most common complication of PFB [13]. As indicated by a previous retrospective cohort study, SpO2≤94 % during bronchoscopy was an independent risk factor for post-bronchoscopy respiratory adverse events [14]. The following steps were undertaken in case of hypoxemia in the present study: (1) If the SpO2 decreased to 85%–90 %, the anesthesiologist would increase the oxygen flow rate to 5 L/min through the existing OA or NA and perform a jaw lift maneuver to improve airway patency. (2) If the SpO2 dropped below 85 %, a fiberoptic laryngoscope would be inserted to establish a definitive airway and provide immediate oxygenation. (3) In cases where the SpO2 remained below 85 % for more than 1 min despite the above interventions, mask ventilation with positive pressure would be initiated after the removal of the fiberoptic bronchoscope. (4) If hypoxemia persisted even with mask ventilation, endotracheal intubation would be performed.

2.4. Outcome measurements

The medical histories of patients, including comorbidities such as hypertension, diabetes, and heart disease, were collected in the anesthesia preparation room. We also recorded patient age, height, weight, and MET and measured their neck and abdominal circumferences. Additionally, we calculated and evaluated the body mass index (BMI) and ASA classification and determined the neck circumference/height ratio (NHR). The vital signs, including MAP, HR, and SpO2, were monitored at different time points: pre-anesthesia (T1), post-anesthesia induction (T2), immediately upon the fiberoptic bronchoscope reaching the tracheal carina (T3),

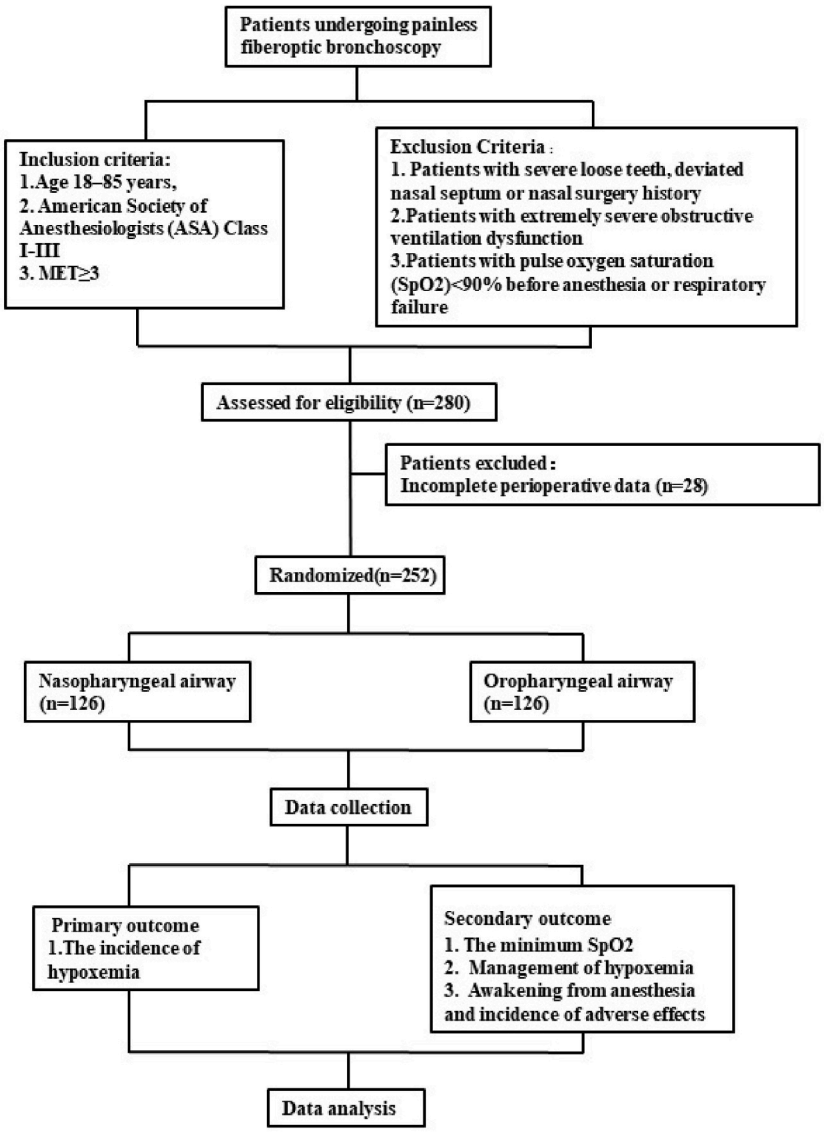

Fig. 1. Flowchart of the present study.

during the fiberoptic bronchoscopy procedure itself (T4), and finally, 5 min after transfer to the post-anesthesia care unit (PACU) (T5).

Hypoxemia is defined as a condition where the oxygen saturation level in the blood is below 90 %. We recorded the frequency and incidence of hypoxemia, the minimum SpO2 (Min SpO2), and the number of patients that required the jaw-thrust maneuver, rapid oxygenation, mask pressurized ventilation or endotracheal intubation. We also recorded whether a patient experienced hypotension requiring vasopressor treatment. The anesthetic dosage, operation times, and patients' awakening were carefully recorded, including whether the modified observer's assessment of alert/sedation (MOAA/S) was ≥4 within 1 min after flumazenil antagonism and the time to leave the PACU (within 1 h) after awakening. The MOAA/S scale is a validated 6-point scale that evaluates patient responsiveness along the ASA sedation continuum [15]. A score of 5 indicated a quick response to their name spoken normally, while 0 indicated no reaction to a painful trapezius squeeze.

2.5. Primary and secondary outcomes

The primary outcome of our study was the incidence and frequency of perioperative hypoxemia and the Min SpO2 during PFB.

Secondary outcomes included comparisons of vital signs at various time points (T1-T5), the incidence of adverse events (AEs), and patient awakening times between the OA and NA groups.

2.6. Sample size estimation

After conducting a literature review, we determined the sample size required for the study based on the incidence of hypoxemia during painless gastroscopy. It has been reported that the incidence of hypoxemia is 4.4 % with OA [16] and 15.9 % with NA [9]. Using a one-tailed test, a P-value of 0.025, and a power value of 0.8, we used PASS 2021 software to estimate the sample size for the study, with the NA and OA groups being in a 1:1 ratio. The sample size required was 210 patients (n = 105 per group). Given that approximately 20 % of patients were expected to drop out, 252 patients were enrolled in the study, with 126 in the NA group and 126 in the OA group.

2.7. Statistical analysis

Statistical analysis was conducted using SPSS version 23.0 (SPSS Inc., Chicago, US). Quantitative data were described as the mean ± SD, and an independent sample *t*-test was used to compare the two groups. Intraoperative anesthetic drugs and other drug concentrations were presented as medians (interquartile range) and analyzed using the Mann-Whitney test. Categorical data are described as numbers or frequencies (%), and $\chi 2$ or Fisher's exact test was used to compare both groups when appropriate. Correlation analysis was performed by the partial correlation test. $P < 0.05$ was considered statistically significant.

Table 1
Baseline characteristics of the study participants.

Group	NA	OA	*P*-value
Age (years)	60.91 ± 10.94	58.80 ± 10.14	0.11
Gender (F/M)	40/86	39/87	0.89
Height (cm)	162.90 ± 7.90	162.82 ± 7.48	0.94
Weight (kg)	60.26 ± 9.45	61.81 ± 9.86	0.21
BMI (kg/m^2)	22.71 ± 2.98	23.32 ± 3.09	0.12
Neck circumference (cm)	38.32 ± 4.28	38.65 ± 4.79	0.57
Abdominal circumference (cm)	86.63 ± 8.66	87.54 ± 11.90	0.49
NHR	0.23 ± 0.33	0.23 ± 0.40	0.98
MET	5.67 ± 1.78	5.99 ± 1.38	0.16
ASA classification			0.34
I	11	9	
II	77	88	
III	38	29	
Type of procedure			0.938
BAL	38(30.2 %)	41(32.5 %)	
transbronchial biopsy	33(26.2 %)	35(27.8 %)	
EBUS-TBLB	34(26.9 %)	31(24.6 %)	
EBUS-TBNA	21(16.7 %)	19(15.1 %)	
Comorbid conditions, n (%)			
Hypertension	36 (28.6)	41 (32.5)	0.49
Diabetes mellitus type 2	10 (7.9)	13 (10.3)	0.59
Coronary artery disease	8 (6.3)	8 (6.3)	/

Continuous variables are reported as the mean ± SD and/or median (range). Comparisons between the two groups were performed using an unpaired *t*-test. Categorical data are reported as numbers or frequencies (%) and a χ^2 or Fisher's exact test was used to compare the two groups when appropriate.

BMI: body mass index; MET: metabolic equivalent; NHR: neck circumference/height ratio; NA: nasopharyngeal airway; OA: oropharyngeal airway; F/M: female/male; BAL: bronohoalveolar lavage; EBUS-TBLB: endobronchial ultrasound-guided transbronchial lung biopsy; EBUS-TBNA: endobronchial ultrasound-guided transbronchial needle aspiration.

3. Results

3.1. Baseline characteristics of the study participants

A total of 252 patients from our institution were enrolled in this prospective, randomized controlled trial (illustrated in Fig. 1) after assessment of 280 patients for eligibility. Patients for whom complete perioperative data could not be obtained were excluded (n = 28). Table 1 summarizes the morphometric, demographic, and baseline clinical characteristics of the patients in each group. No significant differences were observed between the OA and NA groups in terms of age, height, weight, BMI, MET, ASA classification, neck circumference, abdominal circumference, NHR, or comorbidities (Table 1). The fiberoptic bronchoscopy procedures in this study included bronchoalveolar lavage (BAL), transbronchial biopsy, endobronchial ultrasound-guided transbronchial lung biopsy (EBUS-TBLB), and endobronchial ultrasound-guided transbronchial needle aspiration (EBUS-TBNA). The number of procedures performed (BAL, transbronchial biopsy, EBUS-TBLB and EBUS-TBNA) did not differ statistically between the OA and NA groups (Table 1). Similarly, the intraoperative doses of remimazolam besylate and operative times did not show significant differences between the groups (Table 2). Notably, the operative times for the OA group (mean ± SD: 31.04 ± 18.95 min) and NA group (mean ± SD: 34.18 ± 19.26 min) were comparable (Table 2).

3.2. SpO2 alterations and airway maintenance following hypoxemia in both groups

This study revealed a significantly lower incidence of hypoxemia in the OA group compared to the NA group (38.8 % vs. 59.6 %, $\chi 2 = 10.73$, $P = 0.001$). Further analysis of hypoxemia risk by procedure type demonstrated a significant decrease in patients undergoing EBUS-TBLB (20/44 vs. 8/23, $P = 0.007$) and EBUS-TBNA (16/41 vs. 8/11, $P = 0.02$) in the OA group. However, no such decrease was

Table 2
Anesthetic drugs, respiratory and hemodynamics parameters in the two groups.

	NA	OA	*P*-value
Anesthetic drugs and operative time			
Remimazolam besylate (mg)	27 (20–40)	26.8 (20~38.5)	0.95
Operative time (minutes)	34.18 ± 19.26	31.04 ± 18.95	0.20
Respiratory parameters			
SpO_2 (%, T1)	97.23 ± 1.53	97.55 ± 1.33	0.08
SpO_2 (%, T2)	97.84 ± 2.19	97.96 ± 2.05	0.65
SpO2 (%, T3)	94.47 ± 5.88	96.09 ± 4.20	0.01✱
SpO_2 (%, T4)	96.54 ± 2.78	96.79 ± 2.49	0.46
SpO_2 (%, T5)	98.06 ± 9.31	97.33 ± 2.40	0.39
Hypoxemia (Y/N)	75/51	49/77	0.001✱✱
Hypoxemia of BAL (Y/N)	23/15	16/26	0.06
Hypoxemia of transbronchial biopsy (Y/N)	16/17	17/18	0.99
Hypoxemia of EBUS-TBLB (Y/N)	20/14	8/23	0.007**
Hypoxemia of EBUS-TBNA (Y/N)	16/25	8/11	0.02*
Minimum SpO_2	87.02 ± 7.89	90.00 ± 5.61	<0.0001✱✱✱✱
Frequency of hypoxemia	1(0,1)	0(0,1)	0.006✱✱
Frequency of hypoxemia in BAL	1(0,1)	0(0,1)	0.29
Frequency of hypoxemia in transbronchial biopsy	0(0,1)	0(0,1)	0.83
Frequency of hypoxemia in EBUS-TBLB	1(0,2)	0(0,1)	0.15
Frequency of hypoxemia in EBUS-TBNA	1(1,2)	0(0,1)	0.17
Times of jaw lifting	1(0,2)	1(0,1)	0.03✱
Times of rapid oxygenation	0(0,1)	0(0,1)	0.07
Mask pressurized ventilation	0	0	/
Endotracheal intubation	0	0	/
Hemodynamics parameters			
MAP (mmHg, T1)	98.66 ± 13.68	101.24 ± 11.74	0.11
MAP (mmHg, T2)	95.20 ± 12.84	98.66 ± 13.68	0.57
MAP (mmHg, T3)	100.86 ± 20.07	102.08 ± 19.00	0.70
MAP (mmHg, T4)	90.42 ± 12.31	90.20 ± 14.02	0.89
MAP (mmHg, T5)	95.51 ± 15.97	93.10 ± 14.86	0.22
HR (beats per min, T1)	84.97 ± 14.65	86.15 ± 15.59	0.54
HR (beats per min, T2)	87.57 ± 13.17	87.31 ± 12.56	0.88
HR (beats per min, T3)	99.31 ± 13.96	101.40 ± 15.11	0.26
HR (beats per min, T4)	88.12 ± 11.56	88.18 ± 12.61	0.97
HR (beats per min, T5)	85.86 ± 13.12	85.30 ± 13.76	0.74

Continuous and categorical (ordinal) variables are reported as the mean ± SD and/or median (range); comparisons between the two groups were performed using an unpaired *t*-test or a Mann-Whitney test.
HR: heart rate; MAP: mean arterial pressure; SpO_2: pulse oxygen saturation; NA: nasopharyngeal airway; OA: oropharyngeal airway; BAL: bronchoalveolarlavage; EBUS-TBLB:endobronchial ultrasound-guided transbronchial lung biopsy; EBUS-TBNA:Endobronchial ultrasound-guided transbronchial needle aspiration.
*P < 0.05, **P < 0.01, ****P < 0.0001.

observed for patients undergoing BAL or transbronchial biopsy (Table 2). There were no significant differences in SpO2 between the OA and NA groups at baseline (T1), after anesthesia induction (T2), during bronchoscopy (T4), or 5 min post-PACU admission (T5). However, SpO2 measured immediately after the fiberoptic bronchoscope reached the carina (T3) was significantly higher in the OA group compared to the NA group ($t = 2.50$, $P = 0.01$, Table 2). This finding was further supported by a higher minimum SpO2 observed in the OA group ($t = 3.57$, $P < 0.0001$, Table 2). Consistent with the lower incidence of hypoxemia, the OA group also exhibited a statistically significant reduction in the frequency of hypoxemia events ($P = 0.006$, Table 2). However, further analysis of hypoxemia frequency by procedure type did not reveal significant differences between the groups (Table 2). Management of hypoxemia events also differed between groups. The NA group required a significantly higher frequency of jaw thrust maneuvers ($P = 0.03$, Table 2). While the use of rapid oxygenation appeared to be more frequent in the NA group ($P = 0.07$, Table 2), this difference did not reach statistical significance. Importantly, no patients in either group required mask ventilation or endotracheal intubation. Additionally, no significant differences were observed in hemodynamic parameters (MAP and HR) at any time point between the NA and OA groups (Table 2).

3.3. Correlation analysis of min SpO2 and the physical parameters of study participants

To investigate the relationship between hypoxemia and body composition, we analyzed the correlations between Min SpO2 and various body parameters (BMI, neck circumference, abdominal circumference, and NHR) during PFB. Partial Least Squares (PLS) modeling was employed for this correlation analysis. Additionally, we considered the potential influence of factors known to affect patient oxygenation during bronchoscopy, including ASA classification [17], age [18], and operation time [19], during the statistical analysis. Our findings revealed a significant negative correlation between BMI and Min SpO2 in all patients undergoing PFB (Fig. 2A, r $= -0.13$, $P = 0.04$). This indicates that higher BMI is associated with lower minimum oxygen saturation levels. However, no significant correlations were observed between NHR, neck circumference, or abdominal circumference and Min SpO2 (Fig. 2B, r $= -0.06$, $P =$ 0.40; Fig. 2C, r $= 0.006$, $P = 0.93$; Fig. 2D, r $= -0.08$, $P = 0.22$).

To investigate the factors that potentially contributed to the difference in hypoxemia between the two groups, fiberoptic bronchoscopy was used to measure the distance between the OA and NA and the glottis in patients of varying heights and genders (Fig. 3A–I). Fig. 3A–C displays fiberoptic bronchoscope images of male patients with varying heights (160–180 cm) after placing nasopharyngeal airway, while Fig. 3D–E exhibit representative photos of female patients ranging from 150 cm to 160 cm in height with fiberoptic bronchoscope after placing nasopharyngeal airway. These results indicate that the distance between the glottis and NA

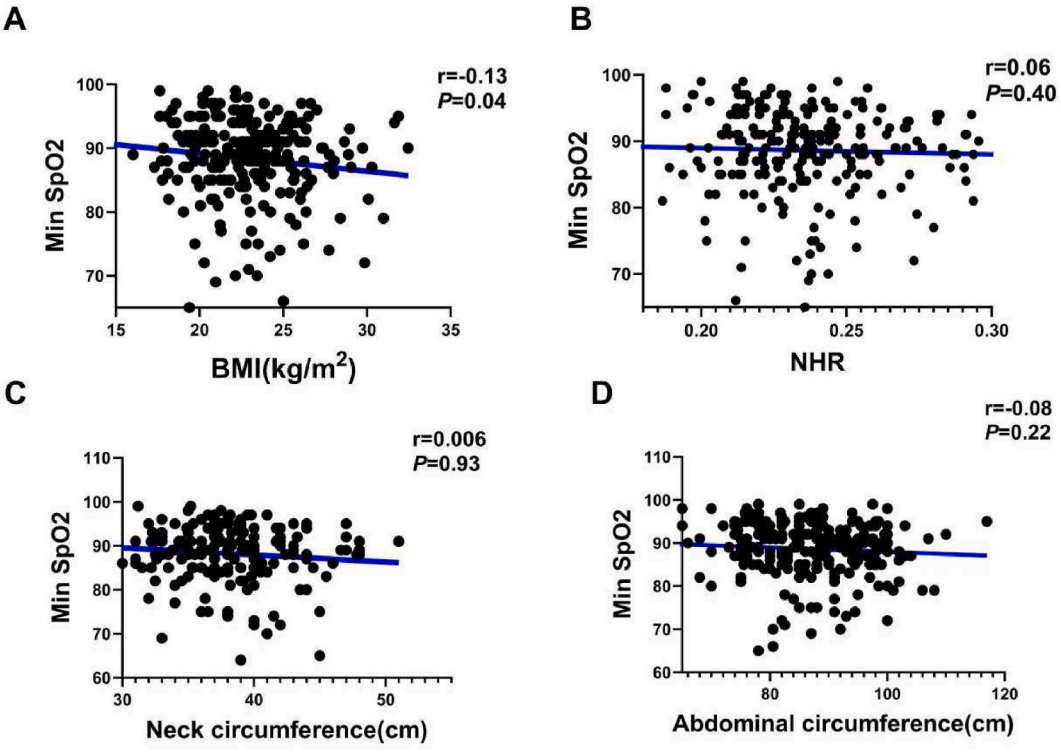

Fig. 2. Correlation analysis of Min SpO2 and physical parameters of patients. A: The BMI of all patients had a certain correlation with Min SpO2 during the examination. B–D: The patients' neck circumference, NHR, and abdominal circumference had no significant correlation with Min SpO2. BMI: body mass index; Min SpO2: minimum pulse oxygen saturation; NA: nasopharynx airway; NHR: neck circumference/height ratio; OA: oropharynx airway.

varied among patients (Fig. 3A–E). Representative pictures of patients with varying heights ranging from 150 cm to 170 cm were also recorded (Fig. 3F–H). In addition, the location of the oxygen tube in the OA group was recorded (Fig. 3I), which indicated that the oxygen tube was positioned very close to the glottis. Fig. 3J shows photos of the oropharyngeal and nasopharyngeal airways of different models used in the study. The top one is the OA, the middle in green is the 6F NA with an external diameter of 25FR, and the bottom in orange is the 7F NA with an external diameter of 29FR. When the SpO2 was <85 %, the fiberoptic laryngoscope, connected to the oxygen tube, is inserted into the main airway to facilitate rapid oxygenation (Fig. 3K), as mentioned earlier.

3.4. Awakening from anesthesia and the incidence of AEs in the two groups

After flumazenil antagonism of the anesthetic, nearly 97 % of patients were awake within 1 min. The proportion of patients who did not open their eyes within 1 min after flumazenil administration did not significantly differ between the two groups (Table 3). Three patients experienced delayed awakening in the PACU, but the difference was not statistically significant between the two groups (Table 3). During PFB, 12.6 % of patients in the OA group and 16.7 % in the NA group experienced hypotension, but there was no significant difference between the two groups (Table 3). The administration of M-hydroxylamine effectively increased blood pressure, and neither group experienced epistaxis or oral bleeding, allergic reactions, or severe hypotension (Table 3).

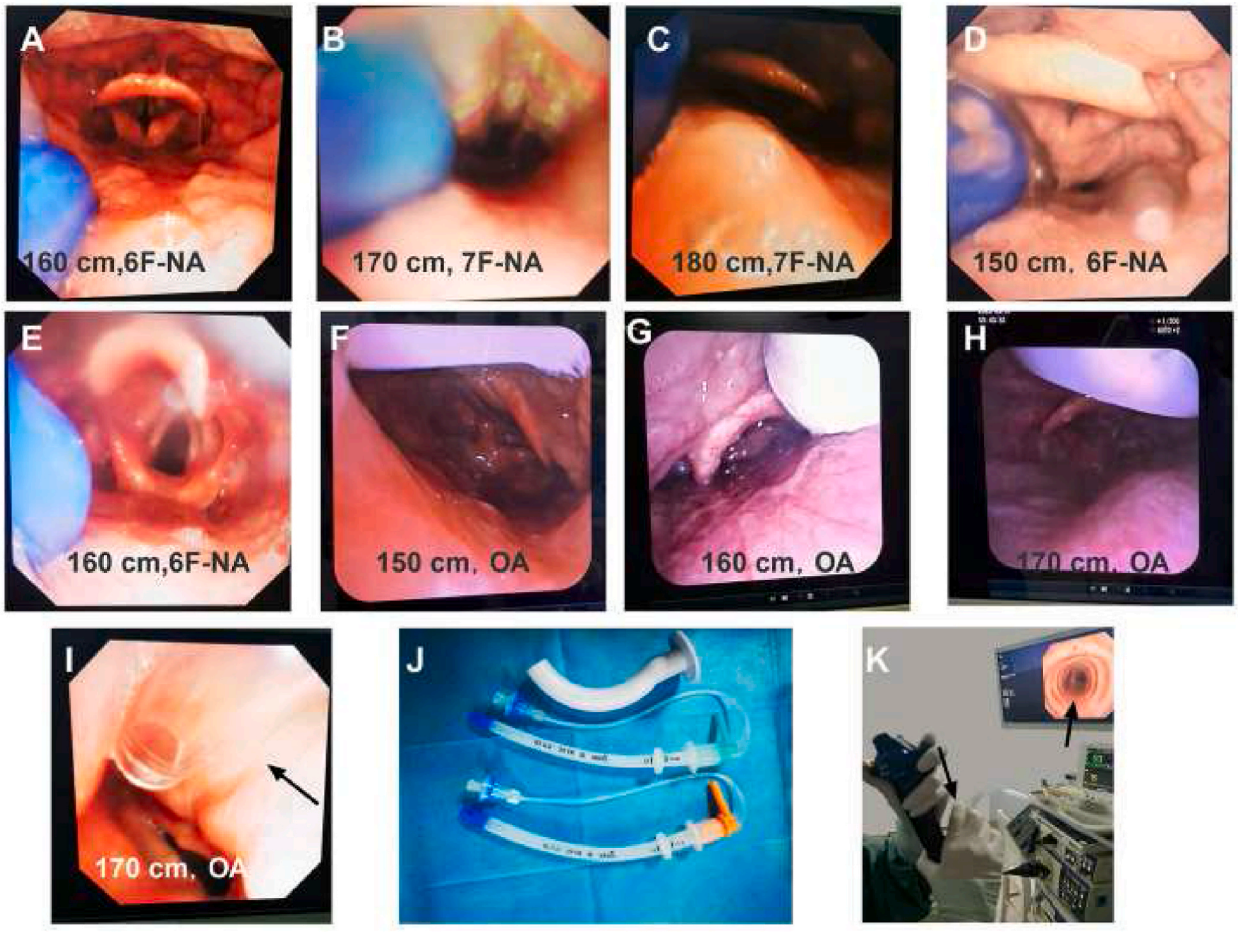

Fig. 3. Representative images of the nasopharynx or oropharynx airway placed in patients of different heights and genders.
A- C shows pictures of male patients of different heights (160 cm–180 cm) with fiberoptic bronchoscope after placing nasopharyngeal airway; D-E shows photos of female patients of different heights (150 cm–160 cm) with fiberoptic bronchoscope after placing nasopharyngeal airway. F–H: Representative pictures of varying heights (ranging from 150 cm to 170 cm) that underwent placement of oropharyngeal airways. I: After placing the oropharyngeal airway, the oxygen tube in the oropharyngeal airway group was very close to the glottis. J: Photos of the oropharyngeal airway and nasopharyngeal airway of different models. The upper one is the oropharynx airway. The nasopharyngeal airway with green color is 6F, and the orange color is 7F; K: Picture of the fiberoptic laryngoscope pushed into the main airway to produce rapid oxygenation when SpO2 is <85 %.
NA: nasopharyngeal airway; OA: oropharyngeal airway.

Table 3
Awakening from anesthesia and the incidence of adverse effects in the two groups.

Group	NA	OA	P-value
Open eyes within 1 min, n (%)	122 (96.8)	122 (96.8)	1
Delayed awaken in PACU, n (%)	2 (1.6)	1 (0.8)	0.56
Patients need m-hydroxylamine, n (%)	21 (16.7)	16 (12.6)	0.37
Epistaxis	0	0	/
Oral bleeding	0	0	/
Allergic reaction	0	0	/
Severe hypotension	0	0	/

Categorical data were described as number or frequencies (%), and a $\chi 2$ or Fisher's exact tests were used for comparison between the two groups when appropriate.
NA: nasopharyngeal airway; OA: oropharyngeal airway.

4. Discussion

The present study observed higher Min SpO2 and SpO2 at T3 in the OA group and a lower incidence of hypoxemia compared to the NA group during PFB, highlighting the superior biosafety profile of OA in maintaining patient oxygenation, which is worthy of clinical promotion.

Fiberoptic bronchoscopy conducted via the airway can potentially result in partial obstruction, elevated airway resistance, and decreased alveolar ventilation and flow rate, which may ultimately lead to hypoxemia, arrhythmia, and potentially even cardiac arrest [20]. Therefore, hypoxemia is most likely to occur in sedated patients and those given local anesthesia during bronchoscopy. Hypoxemia, a complication with a reported prevalence ranging from 26 % to 68.1 % in patients undergoing bronchoscopy, can be attributed to variations in anesthesia selection and inconsistent criteria for defining hypoxemia [12,21–23]. In the present research, the overall incidence of hypoxemia in patients undergoing PFB was 48.4 %, with a higher rate in the NA group than in the OA group (59.6 % vs. 38.8 %).

The causes of hypoxemia during PFB are relatively complex, including patient respiratory system disease, the use of anesthetic drugs, breath holding, cough, laryngospasm, bleeding, etc. [23]. Additionally, Chen H et al. suggest that factors such as patient comorbidities, the degree of airway stenosis, and the bronchoscopist's skill level may also influence the incidence of hypoxemia [21]. Most anesthetics used for sedation during PFB can cause glossoptosis and respiratory depression. Therefore, ventilation following anesthesia is crucial for successful fiberoptic bronchoscopy. The OA is a medical device used in airway management to maintain or open a patient's airway. The OA can prevent the tongue from covering the epiglottis and establish a temporary artificial airway [3]. The NA is a thin, clear, flexible tube inserted into a patient's nostril [24]. The NA aims to circumvent blockage of the upper airway at the level of the nose, nasopharynx, or base of the tongue. Additionally, it prevents the tongue from retracting towards the pharyngeal wall and causing an obstruction. The NA preserves the openness of the airway in patients who are conscious or semi-conscious. The current study suggests that OA is more effective than NA in maintaining patient oxygenation. The possible explanations for this finding are: firstly, OA significantly reduces the degree of posterior tongue displacement, resulting in better airway opening; secondly, the oxygen tube is positioned closer to the glottis with the use of OA, resulting in more accurate delivery of oxygen.

Next, the correlation between hypoxemia and BMI, neck circumference, NHR, and abdominal circumference was analyzed. There was a clear correlation between BMI and hypoxemia during endoscopy. Obese patients were more susceptible to hypoxemia than those of normal weight [6]. The results of the present study provide compelling evidence of a significant negative correlation between Min SpO2 and BMI during painless bronchoscopy in the NA and OA groups, but not with neck circumference, NHR, or abdominal circumference. It has been reported that neck circumference is closely associated with apnea syndrome severity [7]. In addition, NHR can predict sleep-related respiratory diseases [15]. The neck circumference [25] and BMI are useful anatomical parameters for predicting complex airway management [26]. Current evidence suggests that patients with a large neck circumference or high BMI [25] may be at a higher risk of developing hypoxemia. However, the results of the present study indicated that neck circumference and NHR had no significant correlation with Min SpO2 during the bronchoscopy procedure.

Traditional opioids combined with propofol [27] or dexmedetomidine [28] are often used during PFB, effectively reducing the severity of cardiovascular reactions and the stress reactions of patients elicited by noxious stimuli. However, some problems remain, such as respiratory inhibition or delayed awakening. Remimazolam besylate is widely used during painless gastroscopy [29] and PFB [30] due to its rapid onset, light inhibition of respiratory, and rapid antagonism by flumazenil. A recent study [30] demonstrated that remimazolam besylate could assist patients in achieving the required level of sedation for bronchoscopy. Ultrasound bronchoscopy may lead to poor recovery quality due to the extended operation time and simple remimazolam besylate sedation. A previous study pointed out that prolonged use of remimazolam besylate for sedation may cause delayed awakening [31]. In the present study, 3 patients did not open their eyes within 1 min after anesthetic antagonism by flumazenil. These patients had a MOAA/S score of fewer than four points and underwent a surgical procedure lasting more than 1 h. Moreover, one female patient was observed in the PACU for $>$1 h due to severe nausea and vomiting. In addition, 14.8 % of patients in the study (12.6 % in the OA group and 16.7 % in the NA group) received a vasopressor to maintain normal blood pressure, which may be related to the prolonged fasting and drinking times, inadequate liquid supplementation, and the vasodilator effect of anesthetic drugs. However, neither group of patients experienced severe hypotension. In addition, no complications such as epistaxis, oral bleeding or allergic reactions occurred in both groups. These results further indicate that remimazolam besylate can be safely used in PFB.

Our study has some limitations that should be acknowledged, including variations in the duration of the examinations, resulting in vital signs being recorded at five specific time points during bronchoscopy following the administration of remimazolam besylate rather than at consistent 5 or 10-min intervals. Moreover, the long-term prognosis of the patients was not observed.

In summary, this study suggests that oropharyngeal airways may be preferable to nasopharyngeal airways for maintaining upper airway patency and reducing the risk of hypoxemia during PFB. The combination of oropharyngeal airways with remimazolam besylate anesthesia during PFB appears to promote stable respiratory function and facilitate rapid patient awakening, offering potential benefits in clinical practice.

Data availability statement

The data are available from the corresponding author (luoruyi@csu.edu.cn) on reasonable request.

Funding statement

The trail was funded by the Scientific project of Hunan Province Health Commission (B202304116531 to RYL) and the Natural Science Foundation of Hunan Province (2024JJ5503 to RYL).

CRediT authorship contribution statement

Pei Zhou: Writing – review & editing, Writing – original draft, Conceptualization. **Di Fu:** Writing – review & editing, Writing – original draft, Data curation, Conceptualization. **Cong Luo:** Data curation, Conceptualization. **Ru-Ping Dai:** Supervision, Conceptualization. **Ru-Yi Luo:** Writing – review & editing, Writing – original draft, Supervision, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

None.

References

[1] S. Qanash, O.A. Hakami, F. Al-Husayni, A.G. Gari, Flexible fiberoptic bronchoscopy: indications, diagnostic yield and complications, Cureus J Med Science 12 (2020) e11122, https://doi.org/10.7759/cureus.11122.
[2] M.A. Pritchett, K. Lau, S. Skibo, K.A. Phillips, K. Bhadra, Anesthesia considerations to reduce motion and atelectasis during advanced guided bronchoscopy, BMC Pulm. Med. 21 (2021) 240, https://doi.org/10.1186/s12890-021-01584-6.
[3] I.A. Du Rand, J. Blaikley, R. Booton, N. Chaudhuri, V. Gupta, S. Khalid, et al., British Thoracic Society guideline for diagnostic flexible bronchoscopy in adults: accredited by NICE, Thorax 68 (Suppl 1) (2013) i1–i44, https://doi.org/10.1136/thoraxjnl-2013-203618.
[4] H. Li, N. Zhang, K. Zhang, Y. Wei, Observation of the clinical efficacy of dexmedetomidine in flexible bronchoscopy under general anesthesia: clinical case experience exchange, J. Int. Med. Res. 47 (2019) 6215–6222, https://doi.org/10.1177/0300060519880763.
[5] Q. Li, J. Sun, X. Shuai, J. Ren, X. Chen, Analysis of diagnostic characteristics and clinical related factors of 70 patients with atelectasis by painless bronchoscopy, Pakistan J. Med. Sci. 38 (2022) 1534–1539, https://doi.org/10.12669/pjms.38.6.5273.
[6] U. Galway, A. Zura, S. Khanna, M. Wang, A. Turan, K. Ruetzler, Anesthetic considerations for bronchoscopic procedures: a narrative review based on the Cleveland Clinic experience, J. Thorac. Dis. 11 (2019) 3156–3170, https://doi.org/10.21037/jtd.2019.07.29.
[7] D. Alon, B. Pertzov, E. Gershman, M. Frishman, N.A. Rahman, D. Rosengarten, et al., The safety of laryngeal mask airway-assisted bronchoscopy versus standard nasal bronchoscopy, Respiration 93 (2017) 279–284, https://doi.org/10.1159/000456551.
[8] W. Zhang, C. Zhu, X. Chen, L. Tao, K. He, H. Wu, et al., Comparison of the innovative endoscopic oropharyngeal airway and the conventional mouthpiece in elderly outpatients undergoing esophagogastroduodenoscopy under sedation: a prospective and randomized study, BMC Gastroenterol. 22 (2022) 8, https://doi.org/10.1186/s12876-021-02089-6.
[9] Q. Xiao, Y. Yang, Y. Zhou, Y. Guo, X. Ao, R. Han, et al., Comparison of nasopharyngeal airway device and nasal oxygen tube in obese patients undergoing intravenous anesthesia for gastroscopy: a prospective and randomized study, Gastroent Res Pract 2016 (2016) 2641257, https://doi.org/10.1155/2016/2641257.
[10] S.A. Pierpoint, J.L. Burke, Comparing nasopharyngeal apnoeic oxygenation at 18 l/min to preoxygenation alone in obese patients - a randomised controlled study, J. Clin. Anesth. 88 (2023) 111126, https://doi.org/10.1016/j.jclinane.2023.111126.
[11] C.A. Riccio, S. Sarmiento, A. Minhajuddin, D. Nasir, A.A. Fox, High-flow versus standard nasal cannula in morbidly obese patients during colonoscopy: a prospective, randomized clinical trial, J. Clin. Anesth. 54 (2019) 19–24, https://doi.org/10.1016/j.jclinane.2018.10.026.
[12] B. Zha, Z. Wu, P. Xie, H. Xiong, L. Xu, H. Wei, Supraglottic jet oxygenation and ventilation reduces desaturation during bronchoscopy under moderate to deep sedation with propofol and remifentanil: a randomised controlled clinical trial, Eur. J. Anaesthesiol. 38 (2021) 294–301, https://doi.org/10.1097/EJA.0000000000001401.
[13] J. Carlens, J. Fuge, T. Price, D.S. DeLuca, M. Price, G. Hansen, et al., Complications and risk factors in pediatric bronchoscopy in a tertiary pediatric respiratory center, Pediatr. Pulmonol. 53 (2018) 619–627, https://doi.org/10.1002/ppul.23957.
[14] S.Y. Kim, H.J. Lee, J.K. Lee, T.Y. Park, E.Y. Heo, D.K. Kim, et al., Association between oxygen saturation level during bronchoscopy and post-bronchoscopy adverse events: a retrospective cohort study, Respir. Res. 23 (2022) 144, https://doi.org/10.1186/s12931-022-02063-0.
[15] N.J. Pastis, N.T. Hill, L.B. Yarmus, F. Schippers, M. Imre, W. Sohngen, et al., Correlation of vital signs and depth of sedation by modified observer's assessment of alertness and sedation (MOAA/S) scale in bronchoscopy, J Bronchol Intern Pu 29 (2022) 54–61, https://doi.org/10.1097/LBR.0000000000000784.

[16] L.J. Shao, S.H. Liu, F.K. Liu, Y. Zou, H.J. Hou, M. Tian, et al., Comparison of two supplement oxygen methods during gastroscopy with intravenous propofol anesthesia in obese patients: study protocol for a randomized controlled trial, Trials 19 (2018) 602, https://doi.org/10.1186/s13063-018-2994-8.
[17] K.J. Powers, V. Avadhanula, P.R. Patel, P.K. Sarkar, P. Piedra, N. Zarrin-Khameh, Whole lung lavage: treating pulmonary alveolar proteinosis at the time of COVID pandemic, Respir Med Case Rep 39 (2022) 101707, https://doi.org/10.1016/j.rmcr.2022.101707.
[18] S. Skoczynski, M. Ogonowski, E. Tobiczyk, D. Krzyzak, G. Brozek, A. Wierzbicka, et al., Risk factors of complications during noninvasive mechanical ventilation-assisted flexible bronchoscopy, Adv Med Sci-POLAND 66 (2021) 246–253, https://doi.org/10.1016/j.advms.2021.04.001.
[19] H.T. Kang, S.Y. Kim, M.K. Lee, S.W. Lee, A. Baek, K.N. Park, Comparison between real-time ultrasound-guided percutaneous tracheostomy and surgical tracheostomy in critically ill patients, Crit Care Res Pract 2022 (2022) 1388225, https://doi.org/10.1155/2022/1388225.
[20] S.A. Roodenburg, C. Barends, G. Krenz, E.J. Zeedijk, D.J. Slebos, Safety and considerations of the anaesthetic management during bronchoscopic lung volume reduction treatments, Respiration 102 (2023) 55–63, https://doi.org/10.1159/000528044.
[21] H. Chen, S. Tian, H. Huang, H. Wang, Z. Hu, Y. Yang, et al., A prediction model for risk of low oxygen saturation in patients with post-tuberculosis tracheobronchial stenosis during bronchoscopy, Ther. Adv. Respir. Dis. 17 (2023) 17534666231216573, https://doi.org/10.1177/17534666231216573.
[22] A. Sharluyan, B. Osona, G. Frontera, K.B. Brandstrup, J. Figuerola, I. Sanz-Ruiz, et al., High flow nasal cannula versus standard low flow nasal oxygen during flexible bronchoscopy in children: a randomized controlled trial, Pediatr. Pulmonol. 56 (2021) 4001–4010, https://doi.org/10.1002/ppul.25655.
[23] X. Huang, P. Ai, C. Wei, Y. Sun, A. Wu, Comparison of the effects of esketamine/propofol and sufentanil/propofol on the incidence of intraoperative hypoxemia during bronchoscopy: protocol for a randomized, prospective, parallel-group trial, J. Clin. Med. 11 (2022) 4587, https://doi.org/10.3390/jcm11154587.
[24] C. Scheuermann-Poley, A. Lieber, Studies on the correct length of nasopharyngeal airways in adults: a literature review, J Spec Oper Med 21 (2021) 45–50, https://doi.org/10.55460/GGFN-XJEG.
[25] M. Syed, J. Selickman, M.D. Evans, D. Dries, J.J. Marini, Elastic power of mechanical ventilation in morbid obesity and severe hypoxemia, Respir. Care 66 (2021) 626–634, https://doi.org/10.4187/respcare.08234.
[26] J.L. Apfelbaum, C.A. Hagberg, R.T. Connis, B.B. Abdelmalak, M. Agarkar, R.P. Dutton, et al., 2022 American society of anesthesiologists practice guidelines for management of the difficult airway, Anesthesiology 136 (2022) 31–81, https://doi.org/10.1097/ALN.0000000000004002.
[27] H. Lee, Y.H. Choe, S. Park, Analgosedation during flexible fiberoptic bronchoscopy: comparing the clinical effectiveness and safety of remifentanil versus midazolam/propofol, BMC Pulm. Med. 19 (2019) 240, https://doi.org/10.1186/s12890-019-1004-6.
[28] Y. Bi, Y. Ma, J. Ni, L. Wu, Efficacy of premedication with intranasal dexmedetomidine for removal of inhaled foreign bodies in children by flexible fiberoptic bronchoscopy: a randomized, double-blind, placebo-controlled clinical trial, BMC Anesthesiol. 19 (2019) 219, https://doi.org/10.1186/s12871-019-0892-6.
[29] W. Shi, Y. Cheng, H. He, Q. Fang, Y. Hu, X. Xu, et al., Efficacy and safety of the remimazolam-alfentanil combination for sedation during gastroscopy: a randomized, double-blind, single-center controlled trial, Clin. Therapeut. 44 (2022) 1506–1518, https://doi.org/10.1016/j.clinthera.2022.09.014.
[30] X. Chen, D. Xin, G. Xu, J. Zhao, Q. Lv, The efficacy and safety of remimazolam tosilate versus dexmedetomidine in outpatients undergoing flexible bronchoscopy: a prospective, randomized, blind, non-inferiority trial, Front. Pharmacol. 13 (2022) 902065, https://doi.org/10.3389/fphar.2022.902065.
[31] T. Takemori, Y. Oyama, T. Makino, S. Hidaka, T. Kitano, Long-term delayed emergence after remimazolam-based general anesthesia: a case report, JA Clin Rep 8 (2022) 86, https://doi.org/10.1186/s40981-022-00576-7.