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The role of video-fluoroscopy in the assessment of obstructive sleep apnea patients: comparative study

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Abstract

Background Pre-operative imaging tools play a crucial role in the anatomic assessment of the upper airway and adjacent structures in obstructive sleep apnea patients. The current study was aimed at comparing and correlating the results of videofluoroscopy in evaluating upper airway obstruction in surgically fit obstructive sleep apnea "OSA" patients with fiberoptic nasoendoscopic examination during the awake "Muller's maneuver" and during sleep induced with propofol for better selection of the suitable surgical maneuver. The present study was an observational cross-sectional study of 69 surgically fit OSA patients (36 males and 33 females); their ages ranged between 29 and 65 years with mean age of 45.87 ± 9.68 years. The patients were selected from otorhinolaryngology, phoniatric, and pulmonology outpatient clinics during the period from February 2019 to January 2020.

Results The present study demonstrated that no statistically significant difference was found between the three techniques (video-fluoroscopy, awake fiber-optic nasoendoscopy, and drug-induced sleep nasoendoscopy "DISE") as regards the shape of upper airway collapse at retropalatal, retroglossal, and hypopharyngeal levels in OSA patient (*P*: 0.621, 0.669, and 1.0 respectively). Statistically, a significant difference was observed between video-fluoroscopy, awake fiber-optic nasoendoscopy on one hand, and DISE on the other one regarding the grade of upper airway collapse at all levels (*P*: 0.006, 0.037, and 0.003). It was a mild significant difference in favor of DISE.

Conclusion Video-fluoroscopy is a good, reliable complementary preoperative assessment tool to identify obstruction patterns of the upper airway in OSA patients with quantitative measurements.

Keywords Videofluoroscopy, Obstructive sleep apnea, DISE, Apnea hypopnea index

Background

A disease of repeated episodes of variable degrees of upper airway obstruction either partial (hypopnea) or complete (apnea) that occurs during sleep is called obstructive sleep apnea syndrome (OSA) [1]. OSA can happen at any age; however, prevalence increases in middle and old age. About 24% of males and 9% of females have the breathing symptoms of OSA with or without daytime sleepiness, and about 80–90% of OSA adult patients remain undiagnosed [2].

There are different surgical modalities for the management of OSA, each with its benefits and risks. The

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surgeon has the role for choosing the right type of surgery for each patient [3]. The goal of surgery is to have a stable airway lumen without obstruction and to provide continuous satisfactory airflow in physiological inspiration by lowering the resistance of the airway. This requires accurate diagnosis and a preoperative estimation of upper airway dimensions to select the most suitable surgical maneuver, avoiding overcorrection or under correction of the tailored airway, and getting the best results of the selected surgical maneuver [4]. Imaging tools play a role in the anatomic evaluation of the airway and adjacent structures. OSA is not diagnosed with imaging, but imaging tools can detect risky patients for airways obstruction and other anatomic features that may contribute to OSA [5].

Awake nasoendoscopy using the modified Muller's maneuver "involves voluntary forced inspiratory effort with a closed mouth and nose" can approximate the level and degree of upper airway collapse in OSA patients [6]. Awake nasoendoscopy with modified Muller's maneuver is a simple awake diagnostic tool without need for sedation that could efficiently help surgeons to diagnose the site of upper airway obstruction correctly and would contribute to the decision for surgical technique before going to the operating room. However, efforts made by the patient and different positions might affect it; also, the maneuver may not necessarily reflect obstructions during sleep when performed during wakefulness [7]. The technique of sleep nasoendoscopy which allows direct visualization of obstruction sites in a sleeping patient was first introduced by Croft and Pringle for the evaluation of snoring to benefit suitable cases for surgical intervention [8]. The glory of sleep endoscopy is present in its capability to give a dynamic visibility to the anatomical levels involved in upper airway collapse under circumstances that simulate sleep [8]. Drug-induced sleep endoscopy (DISE) has extent throughout the world and is the desired diagnostic procedure to assess the upper airway of OSA patients in a state that simulates natural sleep. It bypasses the disadvantage of awake endoscopy and can give more correct upper airway estimation. This method needs medical sedation (propofol) and the insertion of a flexible endoscope through the nostril to visualize the upper airway [9]. However, it is an invasive maneuver that requires an operating theater and patient compliance with suitable health conditions for anesthesia and for using the sedating agent. In addition, it does not reflect the accurate closure happening in natural sleep [10].

Multi-view video-fluoroscopy is a radiological method of investigation that was used to evaluate the dynamics of the upper airway during speech [11] and more recently to study OSA subjects [12]. Videofluoroscopy can detect the upper airway mobility and its dynamic changes during sleep; it is a non-invasive method of investigation that can get the collapse happening in different parts and able to image the whole pharyngeal airway in a single plane besides its ability for direct observation the sites of obstruction during episodes of apnea and accessibility of fluoroscopy in most hospitals with a low financial burden [13]. Videofluoroscopy is less invasive and needs less cooperation from the patient than nasoendoscopy and magnetic resonance imaging; this will help in understanding the airway obstruction mechanism and deciding the plans of treatment [14].

This work aimed to compare and correlate the results of video-fluoroscopy in evaluating upper airway obstruction in surgically fit OSA patients with fiberoptic nasoendoscopic examination during the awake "Muller's maneuver" and during sleep induced with propofol for better selection of the suitable surgical maneuver.

Methods

Subjects

This is an observational cross-sectional study of 69 surgically fit OSA patients (36 males and 33 females); their ages ranged between 29 and 65 years with mean age 45.87 ± 9.68 years. The patients were selected from otorhinolaryngology, phoniatric, and pulmonology outpatient clinics during the period from February 2019 to January 2020. Informed written consent was obtained from patients before the start of the study.

Inclusion criteria:

Sixty-nine surgically fit OSA patients were involved in the study with:

(1) Continuous positive airway pressure (CPAP) device failure
(2) CPAP refusal either for psychological or socioeconomic causes

Exclusion criteria:

(1) OSA patients that are associated with other known pulmonary diseases such as chronic obstructive pulmonary disease (COPD), asthma, interstitial lung disease, and bronchiectasis
(2) Previous sleep surgery
(3) Patient with obvious nasal deformities
(4) Morbid obesity: patient with body mass index (BMI > 40)
(5) Pregnant females

Methods

All patients were subjected to the following protocol of assessment:

1. Preliminary diagnostic procedures:

   (A) Patient's interview: searching for symptoms of OSA and applying the STOP-Bang questionnaire (STOP: snoring, tiredness, observed apnea, and high blood pressure and Bang: body mass index, age, neck circumference, and gender) [15].
   (B) Visual assessment of the vocal tract, including:

   - Uvula: either absent, short, bifid, or elongated
   - Tonsil size: according to the modified Friedman staging system [16]
   - Tongue base size: by the modified Mallampati score (MMS) [17]

   (C) Polysomnography (PSG): all patients underwent polysomnography pre-operatively at the sleep lab unit; the apnea–hypopnea index (AHI) determines the severity of OSA; AHI (5–14) is mild degree, AHI (15–29) is moderate, and AHI (≥ 30) is severe [1].

2. Clinical diagnostic aids:

   (A) Multi-view video-fluoroscopy: The examination was done in the fluoroscopic unit, radiology department by a phoniatrician and a radiology technician. A fluoroscopic imaging of the pharyngeal airway was done using a Polystar imaging system (Siemens Medical Solutions, Erlangen, Germany). The followings were considered: the patient was lying in a supine position, a thick barium solution (1 ml) was applied through the nostril by a pipette and the patient was asked to swallow so that barium can envelop the mucous membrane of the soft palate and pharynx. The use of barium contrast was useful in defining small gaps. The examination was conducted in lateral and frontal views during resting respiration and Muller's maneuver and all estimations were measured in millimeters using the video-fluoroscopic ruler. Shape and grade of airway collapse were assessed at retropalatal, retroglossal, and hypopharyngeal levels by summation of the data obtained from both views, and the structures involved in upper airway collapse during Muller's maneuver either single or multiple-level collapses were detected [12].

   * Lateral view: The patient was lying on one side at the video-fluoroscopic table with the mid-sagittal plane perpendicular to the x-ray beam. The fluoroscopic table is focused so that the field of exposure should include the lips anteriorly, the nasopharynx superiorly, the posterior pharyngeal wall posteriorly, and the epiglottis inferiorly. This view could show the followings: structures involved in upper airway collapse during Muller's maneuver either (single or multiple-level collapses), the lateral shape of the upper airway lumen during Muller's maneuver at the retropalatal level, either (tunnel or funnel-shaped), degree of collapse between the soft palate and posterior pharyngeal wall, soft palatal length, space between the soft palate and posterior pharyngeal wall at rest and during Muller's maneuver (retropalatal level), the distance between the tongue base and posterior pharyngeal wall at rest and during Muller's maneuver (retroglossal level) and distance between the tip of the epiglottis and posterior pharyngeal wall at rest and during Muller's maneuver (hypopharyngeal level).

   * Frontal view: The patient was lying in a supine position at the video-fluoroscopic table with the mid-sagittal plane parallel to the x-ray beam. This view could show the followings: degree of collapse of lateral pharyngeal walls and distance between the lateral pharyngeal walls at rest and during Muller's maneuver at the position of maximum collapse.

   (B) Awake fibroptic-nasoendoscopy: The examination was done by a phoniatrician through a fibroptic nasoendoscopy "Henke-Sass-Wolf, type10" that connected to a lemke video camera (mc204). The followings were considered before the examination, the phoniatrician gave instructions to the patient about the technique in which Muller's maneuver could be done; the patient should practice until the phoniatrician became sure that the patient was doing a successful Muller's maneuver. After that; the patient was lying in a supine position, nasal decongestant was applied, lubrication using xylocaine gel 2%, and the fibroptic-nasoendoscopy was introduced through the nostril, below the inferior turbinate and sliding over the soft palate where the upper airway starts to be assessed. The shape and degree of upper airway collapse were visualized and reported during both resting position and Muller's maneuver at the retropalatal, retroglossal and hypopharyngeal levels. Shapes of collapse at the retro-palatal, retro-glossal, and hypopharyngeal airway collapse were documented as anteroposterior, lateral, or circular. Degrees of the collapse of retro-palatal, retro-glossal, and hypopharyngeal airway collapse were evaluated as grade I ≤25% collapse of the airway, grade II ≤ 50% collapse of the airway, grade III ≤ 75% collapse of the airway, grade IV ≤ 100% collapse of the airway [18]. The tongue base level was evaluated as either pushing or non-pushing to the epiglottis, also the epiglottic shape was evaluated as either flat, curled, or omega-shaped.

(C) Drug-induced sleep fibroptic-nasoendoscopy (DISE): The examination was done at an operating theatre at the otorhinolaryngology department by an otorhinolaryngologist and an anesthesiologist. The followings were considered: The patient lied on the operating table in a supine position, the patient had basic cardiorespiratory monitoring (blood pressure, pulse oximetry, and electrocardiogram), the objective deepness of sedation is the change from consciousness to unconsciousness (lost response to verbal stimulation), in another term, when the patient was starting to snore and choke. An anticholinergic drug (Atropine) that decreases saliva production during evaluation was used for all patients once 30 minutes before anesthesia at a adjusted dose of 0.6 mg/kg. Propofol was used for sleep induction; it was used in a dose of (1.5 mg/kg) as a bolus and then maintained with a simple manual controlled infusion. Slow stepwise of sleep induction was used to avoid over-sedation as propofol is an ultra-short acting hypnotic that enables more control of the depth of sedation during sleep endoscopy. Progressive declines in both upper airway dilator muscle tone and neuro-muscular reflex activation, that increase the collapsibility of airway, were associated with deeper levels of sedation [19]. For avoiding overestimation of airway collapse, collapses that happened while oxygen saturation was less than the minimal saturation in the PSG were disregarded. A fiberoptic nasopharyngoscope lubricated with lidocaine 2% gel was introduced into the nasal cavity once the patient has reached a acceptable level of sedation and the areas producing snoring and/or obstruction were assessed (the lateral pharyngeal wall, soft palate, tongue base, and larynx). Shapes and degrees of collapse at the retro-palatal, retroglossal, and hypopharyngeal airway collapse were documented as anteroposterior (coronal), lateral (sagittal), or circular (concentric) [20].

Statistical analysis

The collected data was revised, coded, tabulated, and introduced to a PC using the Statistical Package for Social Science (IBM Corp. Released in 2011) (IBM SPSS Statistics for Windows, Version 20.0. Armonk, NY: IBM Corp.). Numbers and corresponding percentages were used for presentation of the qualitative data. Chi-square test was used for comparison between 2 or more variables, the Monte Carlo test as correction for the chi-square test when greater than 25% of cells have a count less than 5 in tables ($>2\times2$), and Fisher exact test was used as a correction for chi-square test when greater than 25% of cells have count less than 5 in 2×2 tables. To measure the relationship between variables, the non-parametric Spearman's rho and parametric Pearson correlation tests were used. *P* value was considered statistically significant if <0.05.

Results

Descriptive and comparative statistics

The current study enrolled 69 surgically fit patients with symptoms of obstructive sleep apnea including (36 males and 33 females) with an age mean equal to 45.87 ± 9.68. At the modified Mallampati score, 3 cases were class IV, 42 cases were class III, 9 cases were class II, and 15 cases were class I. Polysomnography was done for the assessment of AHI (apnea–hypopnea index); 60 cases were severe OSA, 6 cases were moderate OSA, and 3 cases were mild OSA. The minimum value of AHI equaled 10, and the maximum value equaled 60, while the mean was 43.26 ± 12.76.

During videofluoroscopic examination using Muller's maneuver, 66 cases had multiple-level airway collapse, while 3 cases had a single-level collapse (at the retropalatal level). Thirty-six cases had funnel-shaped airway collapse, while 33 cases had tunnel-shaped airway collapse at the retropalatal level (Table 1). Structures involved in the upper airway collapse during Muller's maneuver (either single or multiple levels collapses) and lateral shape of upper airway lumen during Muller's maneuver at the retropalatal level (either tunnel or funnel-shaped) (Fig. 1).

During videofluoroscopic examination at the lateral view, the soft palatal length ranged from 14.4 mm to 56.5 mm with a mean of 34.1 ± 10.77. The distance at rest (normal respiration) between the velum and the posterior pharyngeal wall (retropalatal level) ranged from 4 mm to 14.2 mm with the mean of 9.89 ± 2.82 and during

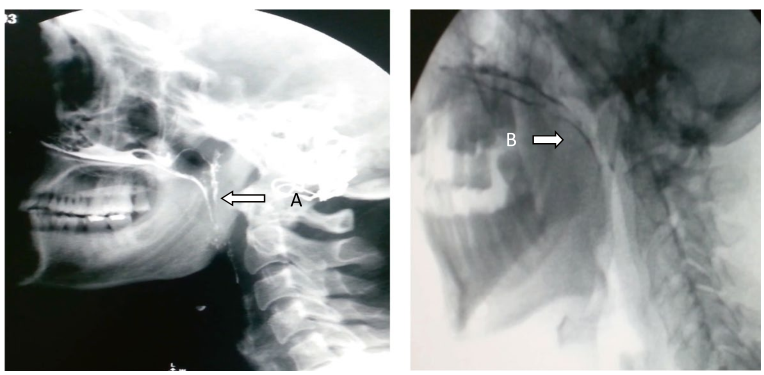
Table 1 Descriptive data obtained from multi-view videofluoroscopy

	N = 69	%
Structures involved in the upper airway collapse during Muller's maneuver		
Single-level collapse	3	4.35%
Multiple-level collapses	66	95.65%
Lateral shape of the upper airway collapse during Muller's maneuver		
Tunnel-shaped lumen	33	47.83%
Funnel-shaped lumen	36	52.17%

Data expressed as number and percentage (%)

Muller's maneuver ranged from 0 mm to 11.3 mm with the mean of 2.75 ± 2.75. The distance at rest between the tongue base and the posterior pharyngeal wall (retroglossal level) ranged from 4.7 mm to 19 mm with a mean of 10.63 ± 3.71 and during Muller's maneuver ranged from 1.4 mm to 13.4 mm with the mean of 4.73 ± 3.19. The distance at rest between the edge of the epiglottis and the posterior pharyngeal wall (hypopharyngeal level) ranged from 6 to 26 mm with the mean of 12.1 ± 5.21 and during Muller's maneuver ranged from 1 mm to 14.9 mm with the mean of 6.44 ± 3.71. At frontal view, the distance at rest between the lateral pharyngeal walls ranged from 13.5 mm to 35 mm with a mean of 17.3 ± 4.32 and during Muller's maneuver ranged from 6.4 mm to 22 mm with a mean of 11.29 ± 3.89 (Table 2) (Fig. 2).

The three techniques (awake fiberoptic nasoendoscopy, video-fluoroscopy, and DISE) showed no statistically significant difference as regards the shape of collapse at retropalatal and retroglossal levels; it was the same shape either circular or coronal by the three assessment methods. There was also no statistically significant difference between awake fiberoptic nasoendoscopy and DISE as regards the shape of collapse at the hypopharyngeal level; however, it is notable to be mentioned that the shape of epiglottis could not be assessed by videofluoroscopy for



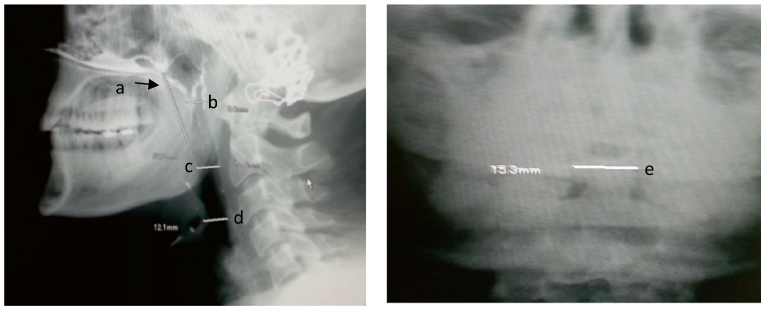
(A) (B)

Fig. 1 Video fluoroscopy, lateral view showing **A** funnel-shaped and **B** tunnel-shaped upper airway collapse during Muller's maneuver

Table 2 Upper airway dimensions in millimeters at rest and during Muller's maneuver in both lateral and frontal views

			Distance in millimeters		
			Minimum	**Maximum**	**Mean ± SD**
Lateral view	Soft palatal length		14.4	56.5	34.1 ± 10.77
	Distance between soft palate and posterior pharyngeal wall	Rest	4	14.2	9.89 ± 2.82
		Muller's maneuver	0	11.3	2.75 ± 2.75
	Distance between tongue base and posterior pharyngeal wall	Rest	4.7	19	10.63 ± 3.71
		Muller's maneuver	1.4	13.4	4.73 ± 3.19
	Distance between tip of epiglottis and posterior pharyngeal wall	Rest	6	26	12.1 ± 5.21
		Muller's maneuver	1	14.9	6.44 ± 3.71
Frontal view	Distance between lateral pharyngeal walls at maximum collapse	Rest	13.5	35	17.3 ± 4.32
		Muller's maneuver	6.4	22	11.29 ± 3.89

Data expressed as mean, *SD* Standard deviation, and range



(A) (B)

Fig. 2 Videofluoroscopy. **A** Lateral view. **B** Frontal view showing upper airway dimensions in millimeters during Muller's maneuver: (a) soft palatal length, (b) distance between soft palate and posterior pharyngeal wall, (c) distance between tongue base and posterior pharyngeal wall, (d) distance between tip of epiglottis and posterior pharyngeal wall, and (e) distance between lateral pharyngeal wall

being 2D radiological imaging. In addition, there was no statistically significant difference between awake fiberoptic nasoendoscopy and videofluoroscopy regarding the grade of airway collapse at all levels. There was a statistically significant difference between awake fiberoptic nasoendoscopy, videofluoroscopy on one hand, and DISE on the other (*P* value less than 0.05%) regarding the grade of collapse at all levels. It was a mild significant difference in favor of DISE (Table 3) (Figs. 3 and 4).

Correlative statistics

There was a statistically significant positive correlation ($P<0.05$) between apnea–hypopnea index (AHI) and grade of airway collapse at the retropalatal level using awake fiberoptic nasoendoscopy, videofluoroscopy, and DISE (Table 4). There was a statistically significant positive correlation ($P<0.05$) between modified Mallampati score (MMS) and grade of airway collapse at a retroglossal level using awake nasoendoscopy, videofluoroscopy, and DISE; there was also a significant positive correlation between MMS and grade of airway collapse at a hypopharyngeal level using DISE; there was also a significant positive correlation between MMS and grade of airway collapse at a retropalatal level using videofluoroscopy (Table 5).

Discussion

This current study enrolled 69 surgically fit patients with symptoms of obstructive sleep apnea including (36 males and 33 females) with an age range from 29 to 65 years old (45.87 ± 9.68). PSG was done for all cases in the current study. AHI (apnea–hypopnea index) was severe in the majority of cases, while 6 cases were moderate and 3 cases were mild. The results of AHI were positively correlated with the degree of upper airway obstruction at the retropalatal level using (awake nasoendoscopy, videofluoroscopy, and DISE). This is in accordance with Herzog et al. study [21] that discussed the association between the AHI and pharyngeal collapse, and they demonstrated a positive association between the AHI and the severity of airway collapse at the retropalatal and retroglossal levels. The majority of cases enrolled in our study had retropalatal airway collapse with a small sample size.

Modified Mallampati score (MMS) was done for all cases (the majority of cases were class III), and results were positively correlated with the severity of upper airway obstruction at a retroglossal level using (awake nasoendoscopy, videofluoroscopy, and drug-induced sleep nasoendoscopy). The results also were positively correlated with the degree of upper airway obstruction at the retropalatal level using videofluoroscopy, which could be explained by the tongue advancement effect (generated during Muller's maneuver) on the retropalatal level causing its collapse. The results also were positively correlated with the degree of upper airway obstruction at the hypopharyngeal level using DISE, which might be due to affection of upper airway dilator muscles happening during sleep (due to insufficient reflex activation of the upper airway) and the gravity effect caused by sleeping in supine position that leads to the backward disposition of the tongue base followed by epiglottic and hypopharyngeal level collapse. This is going in hand with Liistro et al. [22] study that approved the significant correlation between the MMS and the AHI. This is unlike the Campanini et al. study [6] that found that the assessment of the obstruction degree with DISE was generally greater than clinical assessment with MMS due to muscle hypotonias during sleep not present during wakefulness.

The ability of proper detection of the lateral shape of the retropalatal part of the upper airway has been considered a vital issue in preoperative upper airway

Table 3 Comparison among awake nasoendoscopy, videofluoroscopy, and drug-induced sleep endoscopy (DISE) findings regarding the degree and shape of airway collapse

Upper airway level	Awake fiberoptic nasoendoscopy		Videofluoroscopy		DISE		Test of significance
	N = 69	%	*N* = 69	%	*N* = 69	%	
Retro-palatal level							
Grade of collapse							
Grade I	0	0%	3	4.35%	0	0%	*P* = 0.006* p1 = 0.261 p2 = 0.015* p3 = 0.016*
Grade II	6	8.70%	3	4.35%	0	0%	
Grade III	30	43.47%	30	43.47%	21	30.43%	
Grade IV	33	47.83%	33	47.83%	48	69.57%	
Shape of collapse							
Circular	63	91.30%	60	86.96%	63	91.30%	*P* = 0.621 p1 = 0.412 p2 = 1.0 p3 = 0.412
Coronal	6	8.70%	9	13.04%	6	8.70%	
Retro-glossal level							
Grade of collapse							
No collapse	6	8.70%	6	8.70%	3	4.35%	p = 0.037* p1 = 0.970 p2 = 0.041* p3 = 0.046*
Grade I	3	4.35%	3	4.35%	3	4.35%	
Grade II	6	8.70%	6	8.70%	6	8.70%	
Grade III	42	60.86%	45	65.22%	33	47.82%	
Grade IV	12	17.39%	9	13.04%	24	34.78%	
Shape of collapse	*N* = 63		*N* = 63		*N* = 66		
Circular	48	76.19%	48	76.19%	54	81.8%	*P* = 0.669 p1 = 1.0 p2 = 0.432 p3 = 0.432
Coronal	15	23.81%	15	23.81%	12	18.2%	
Hypo-pharyngeal level							
Grade of collapse							
No collapse	12	17.39%	9	13.04%	6	8.70%	*P* = 0.003* p1 = 0.963 p2 = 0.004* p3 = 0.006*
Grade I	6	8.70%	6	8.70%	3	4.35%	
Grade II	21	30.43%	21	30.43%	15	21.74%	
Grade III	24	34.78%	27	39.13%	21	30.43%	
Grade IV	6	8.70%	6	8.70%	24	34.78%	
Shape of epiglottis							
Flat	30	43.48%			30	43.48%	p2 = 1.0
Curled	36	52.17%			36	52.17%	
Omega shaped	3	4.35%			3	4.35%	

Data expressed as number and percentage (%); used tests: *MC* Monte Carlo test

* Significant difference (if $P < 0.05$), *P* is the difference between awake fiberoptic nasoendoscopy, videofluoroscopy, and DISE; p1 is the difference between awake fiberoptic nasoendoscopy and videofluoroscopy; p2 is the significance between awake fiberoptic nasoendoscopy and DISE; p3 is the significance between videofluoroscopy and DISE

assessment as it helps the surgeon select the suitable surgical maneuver. Funnel-shaped airway collapse is a distal isolate palatal collapse that is easy to be corrected by any corrective surgical technique; meanwhile, tunnel-shaped airway collapse is a proximal and distal collapse that necessitates either maxillary mandibular advancement or transpalatal advancement pharyngoplasty [20]. Also, the capability of proper identification of the grade of collapse at each different level of the upper airway has become vital in deciding the correct surgical procedure of OSA patients. The major risk factor predisposing to the surgical failure in patients undergoing single-level surgery (e.g., uvulopalatopharyngoplasty) has been considered the severe retro lingual collapse. Multi-level surgical techniques to OSA surgery have favorable outcomes in comparison with single-level procedures [23]. Therefore, a necessity of accurate pre-operative airway assessment of OSA patients that reflects the true severity

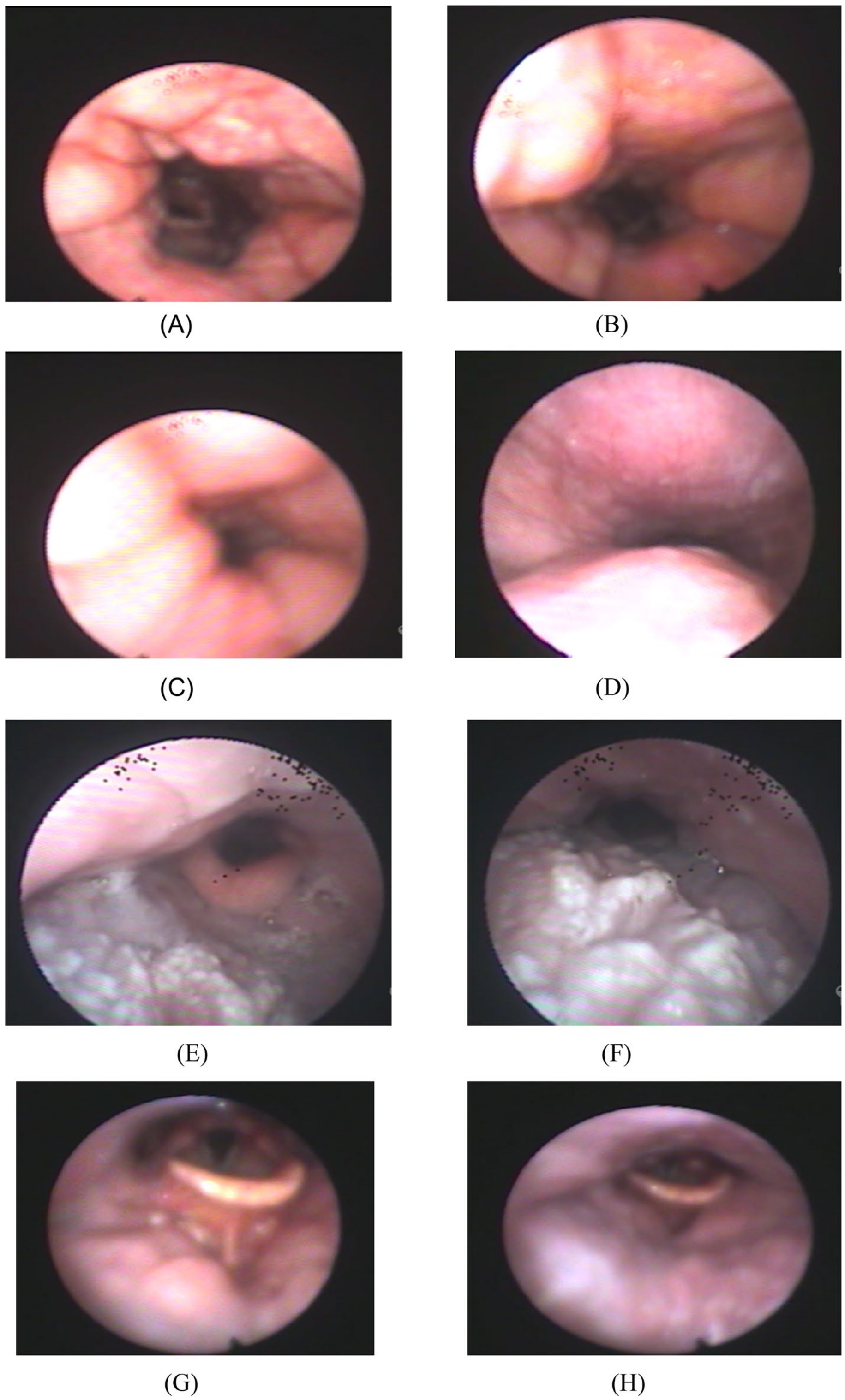


Fig. 3 Awake nasoendoscopy at retro-palatal level (**A**) at rest, (**B**) during Muller's maneuver showing grade II circular collapse, (**C**) during Muller's maneuver showing grade III circular collapse, and (**D**) during Muller's maneuver showing grade III anteroposterior (coronal) collapse. Awake nasoendoscopy at retro-glossal level (**E**) at rest and (**F**) during Muller's maneuver showing grade II circular collapse. Awake nasoendoscopy at hypopharyngeal level (**G**) at rest and (**H**) during Muller's maneuver showing grade III collapse and curled epiglottis

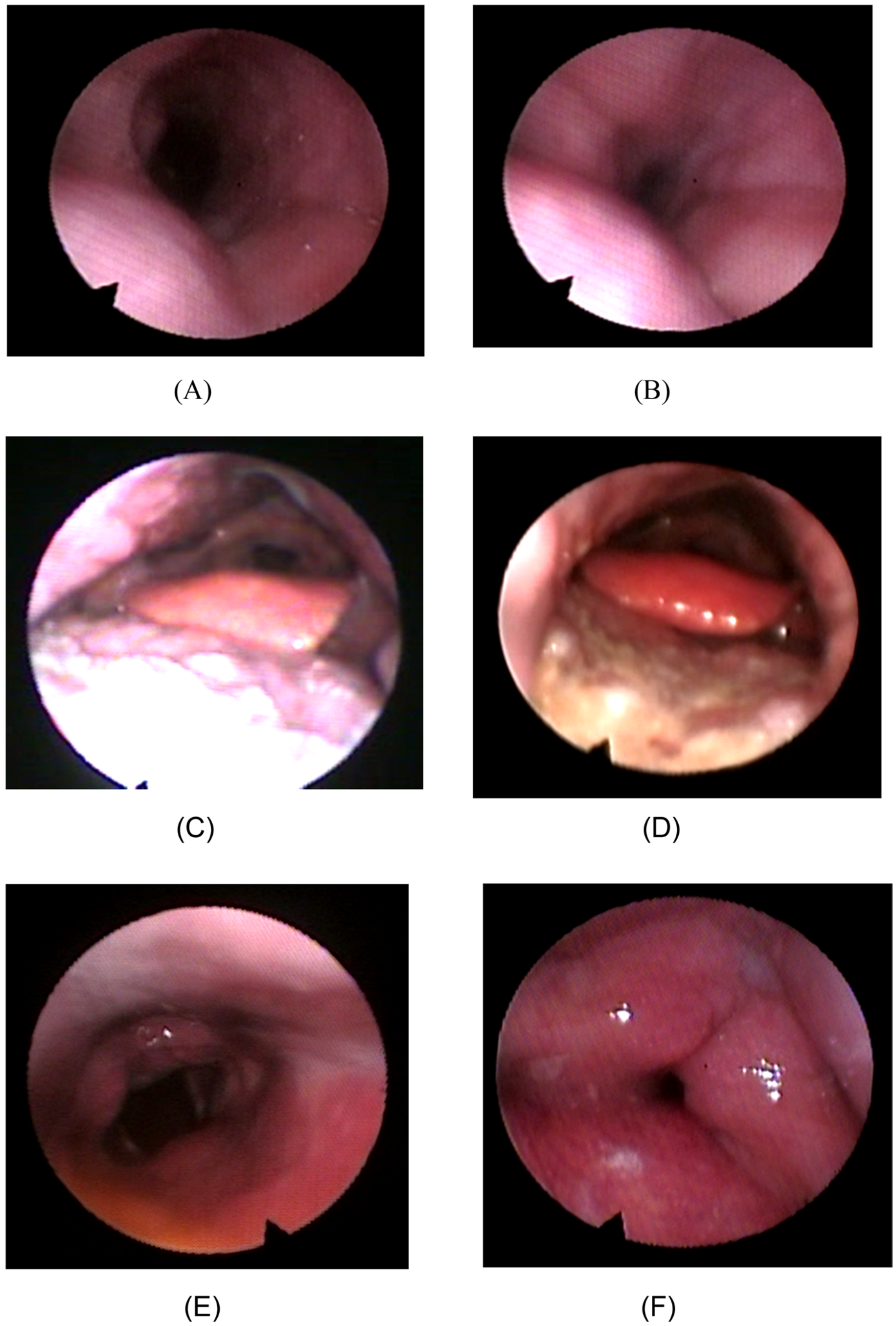


Fig. 4 DISE at retropalatal level (**A**) at rest and (**B**) during snoring grade III circular collapse. DISE at retroglossal level (**C**) at rest and (**D**) during snoring grade II circular collapse. DISE at hypopharyngeal level (**E**) at rest and (**F**) during snoring grade IV collapse

of collapse and the number of structures involved in the collapse that occurs during sleep should be considered in the assessment of OSA patients. So, underestimation of severe collapse interferes with recommending necessary surgical interventions, and overestimation results in the recommendation of unnecessary surgical procedures, and the necessity of multilevel evaluation of the collapse pattern and grade was raised.

In this study, videofluoroscopic examination using Muller's maneuver could detect the lateral shape of the upper airway lumen and the involved level sharing in collapse either single or multiple. The lateral shape of the

Table 4 Correlation between AHI and (awake fiberoptic nasoendoscopy, multi-view videofluoroscopy, and DISE) regarding grade of collapse

Grade of collapse	AHI	
	r	*P*
Awake nasoendoscopy		
Retropalatal level	0.521	0.017*
Retroglossal level	0.14	0.072
Hypopharyngeal level	0.213	0.33
Videofluoroscopy		
Retropalatal level	0.53	0.024*
Retroglossal level	0.39	0.084
Hypopharyngeal level	0.319	0.37
DISE		
Retropalatal level	0.543	0.047*
Retroglossal level	0.351	0.50
Hypopharyngeal level	0.02	0.85

r, Spearman correlation coefficient

* Statistically significant (if $P < 0.05$)

Table 5 Correlation between modified Mallampati score (MMS) and (awake nasoendoscopy, multi-view videofluoroscopy, and DISE) regarding grade of collapse

Grade of collapse	MMS	
	r	*P*
Awake nasoendoscopy		
Retropalatal level	0.33	0.054
Retroglossal level	0.67	0.019*
Hypopharyngeal level	0.29	0.13
Videofluoroscopy		
Retropalatal level	0.38	0.047*
Retroglossal level	0.57	0.023*
Hypopharyngeal level	0.37	0.093
DISE		
Retropalatal level	0.16	0.46
Retroglossal level	0.64	0.041*
Hypopharyngeal level	0.634	0.001*

r, Spearman correlation coefficient

* Statistically significant (if $P < 0.05$)

upper airway lumen during Muller's maneuver at the retropalatal level revealed 36 cases had funnel-shaped airway collapse (distal isolate palatal collapse), while 33 cases had a tunnel-shaped airway collapse (both proximal and distal collapse). This is in accordance with the Lee et al. study [13] that revealed that the most common anatomic structures included in upper airway collapse in OSA patients were the soft palate and the oropharynx respectively. The most common obstructed structure in mild OSA was the soft palate alone, while a combination of the velum and the tongue base was more frequent in severe OSA. Hong et al. study [24] about upper airway evaluation in patients with OSA using videofluoroscopy revealed that the majority of cases had a single structure involved in the airway collapse, while the minority of cases had multiple involved structures. In contrast, our study revealed that the majority of cases had multiple-level airway collapse, and this contrast is attributed to the fact that most of our included patients were severe OSA patients with longstanding synergistic symptoms.

Videofluoroscopy is a noninvasive method that shows dynamic changes in the upper airway at rest and during Muller's maneuver. It is a simple maneuver present in most hospitals, does not need an operating room, can be completed in a short time, and can provide valuable information on the obstructive events of the upper airway. It is a complementary technique that can be easily done, especially for surgeons who need to know how and where the obstruction occurs. It is a useful assessment tool of both the anteroposterior and the transverse airway; it can estimate in millimeters the diameter of the airway during rest and Muller's maneuver as well, which gives a respectable idea about the accurate degree of airway collapse and help the surgeon to detect the proper distance the patient needs to correct for having a patent airway for free breathing during sleep and overcomes overcorrection and sub correction.

In this study, all the patients were examined for upper airway collapse with awake fiberoptic nasoendoscopy, videofluoroscopy, and DISE; there was no statistically significant difference between the three maneuvers regarding the shape of collapse at all levels. Also, there was no statistically significant difference between awake fiberoptic nasoendoscopy and videofluoroscopy regarding the grade of airway collapse at all levels, while there was a statistically significant difference between awake fiberoptic nasoendoscopy, videofluoroscopy on one hand, and DISE on the other one regarding the grade of collapse at all levels. This is going in hand with the Askar et al. study [25] that was done on eighty-one adult subjects with OSA symptoms, with the comparison between positional awake endoscopy vs DISE in the evaluation of OSA, and it revealed that there was a significant difference between the results of Muller's maneuver (sitting and supine positions) and DISE regarding the grade of collapse that was due to lower muscular tone during DISE (as the sleepy state of the patient) and different positional effect as DISE is performed during supine position, while Muller's maneuver is usually done in sitting; the most common level of collapse was the retropalatal level. However, there was no significant difference between the results of Muller's maneuver (sitting and supine positions) and DISE as regards the shape of collapse. In the Ibrahim et al. study [26], they found that DISE was more precise than the Muller maneuver in judging the obstruction shape at the retro-palatal and the retro-glossal level, while it was similar the Muller maneuver in evaluating the obstruction degree at retro-palatal, retro-glossal, and hypopharyngeal levels.

With the analysis of the current study results, it was noticed that the retropalatal level was the most involved in upper airway collapse. It was also found that the difference in the grade of collapse between videofluoroscopic examination and DISE had not exceeded a single grade (for the same patient at the same grade) in the majority of cases. Multi-view videofluoroscopy can provide an accurate preoperative airway assessment with close results to awake fiberoptic nasoendoscopy during Muller's maneuver and relatively close results to DISE; however, there was no single recorded change of the shape of collapse at any level between these techniques. Although videofluoroscopy exposes the patient to radiation, also it is a bi-dimensional technique of investigation, it is non-invasive, it is easily applied, it does not require anesthesia or operating theater, and for sure it is a low-cost technique suitable for developing countries. Moreover, videofluoroscopy provides extra data regarding the estimation of upper airway dimensions, the number of structures involved in the collapse, and a holistic view of the airway collapse either tunnel or funnel-shaped, which serves the target of the surgery, and this was in concordance going with the aim of the research.

In our study, we have limitations in the form of the limited number of included personnel due to limited resources; however, we feel it was reasonable for a preliminary report to include three different research modalities. The drug (propofol) effect on muscle relaxation during DISE and the topical anesthetics (if needed) effect during Muller's maneuver are questionable. The subjective nature of Muller's maneuver and DISE is another matter. Patient compliance during the videofluoroscopic examination was a problem that we overcame with repeated instructions and training before and sometimes during the examination as well. Also, a high radiology dose of videofluoroscopy was a dilemma that resembled a barrier against its employment in children's examination and follow-up.

Conclusion

Videofluoroscopy is a good, reliable complementary preoperative assessment tool to identify obstruction patterns of the upper airway in OSA patients with quantitative measurements. Videofluoroscopy utilizes standard radiographic methods to examine the upper airway that can be used preoperatively to adjust the continuous, dynamic visualization in the lateral and anteroposterior planes of the upper airway, it can detect the pattern and grade of collapse at different levels, it can give an accurate estimation of upper airway dimensions in millimeters, it can show a holistic shape of upper airway either tunnel or funnel, and it can detect the levels of collapse either single or multiple.

Recommendations

The combination of videofluoroscopy, DISE, and awake endoscopy for assessment of OSA patients is recommended as an important preoperative method for upper airway evaluation for better selection of suitable surgical maneuvers. Research is recommended to compare the results of different operative techniques used in OSA management by videofluoroscopy. It is recommended to conduct further studies using videofluoroscopy to compare pre-operative and post-operative results of many surgical techniques for the management of OSA.

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Authors' contributions
HB: design and supervision of the study, interpretation of data regarding awake endoscopic evaluation. AAA: design of the study, analysis and interpretation of awake endoscopic evaluation and videofluoroscopic data, and drafting the manuscript. AMZ: analysis, interpretation of the data of videofluoroscopy, and helping to draft the manuscript. NEM: analysis, interpretation of data regarding PSG. AE: design and supervision of the study, interpretation of DISE data. AA: design and supervision of the study, interpretation of data regarding videofluoroscopy. All authors read and approved the final manuscript.

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Availability of data and materials
Available (the datasets used and/or analyzed during the current study are available from the corresponding author).

Declarations

Ethics approval and consent to participate
This study was performed in line with the principles of the Declaration of Helsinki. Approval was granted by the institutional research board of Mansoura Faculty of Medicine, Mansoura University (MS/16.09.29). Informed written consent was obtained from patients before the start of the study.

Consent for publication
Not applicable.

Competing interests
The authors declare that they have no competing interests.

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