Review Article

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Evaluation of the upper airway in obstructive sleep apnoea

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The evaluation of the upper airway (UA) includes the physical examination of pharyngeal structures and a number of imaging techniques that vary from the mostly used lateral cephalometry and computed tomography to more sophisticated methods such as tri-dimensional magnetic resonance image (MRI). Other complex techniques addressing UA collapsibility assessed by measurement of pharyngeal critical pressure and negative expiratory pressure however are not routinely performed. These methods provide information about anatomic abnormalities and the level of pharyngeal narrowing or collapse while the patient is awake or asleep. Data suggest that individual patients have different patterns of UA narrowing. So, the best method for evaluating obstruction during obstructive events remains controversial. In general, in clinical practice physical examination including a systematic evaluation of facial morphology, mouth, nasal cavity and the pharynx as well as simple imaging techniques such as nasopharyngoscopy and cephalometry have been more routinely utilized. Findings associated with obstructive sleep apnoea (OSA) are UA narrowing by the lateral pharyngeal walls and enlargements of tonsils, uvula and tongue. Additionally cephalometry identifies the most significant craniofacial characteristics associated with this disease. MRI studies demonstrated that lateral narrowing of UA in OSA is due to parapharyngeal muscle hypertrophy and/or enlargement of non adipose soft tissues.

The upper airway evaluation has indubitably contributed to understand the pathophysiology and the diagnosis of OSA and snoring. Additionally, it also helps to identify the subjects with increased OSA risk as well as to select the more appropriate modality of treatment, especially for surgical procedures.

Key words Acoustic reflection - nasopharyngoscopy - negative expiratory pressure - pharyngeal collapse - OSA - upper airway

Obstructive sleep apnoea (OSA) is an increasingly prevalent disease with a considerable social burden with the pathophysiology based on the interaction of multiple factors. Previous studies of OSA have focused primarily on disorders of the upper airway (UA) structure and function, such as fixed anatomical abnormalities, UA dilator muscle dysfunction and instability of breath control. The mechanism of OSA has been related to increased UA collapsibility and reduction of UA size, alterations in craniofacial structure and enlargement of surrounding soft tissue structures (*i.e.,* tongue and lateral pharyngeal walls)[1-3].

This review focuses on the utility of individual UA evaluation tools including physical and functional examination; and the use of imaging methods such as conventional and electron beam computed tomography (CT), magnetic resonance imaging (MRI), acoustic reflection, nasal pharyngoscopy, cephalometry, and fluoroscopy. These techniques provide information about anatomic abnormalities and the level of pharyngeal narrowing or collapse while the patient is awake or asleep. Since individual patients have different patterns of UA narrowing[4]; the best method for evaluating obstruction during obstructive events remains controversial. Although not in the clinical practice, more complex techniques for evaluating UA collapsibility such as measurement of pharyngeal critical pressure and negative expiratory pressure [5] will also be discussed.

In summary, this article reviews useful methods and techniques for UA evaluation in patients with OSA.

Physical examination

Otolaryngology examination focus on pharyngeal anatomy including lateral wall, soft palate, uvula and tongue volume. Facial skeletal characteristics (maxilla, mandible, and dental arch occlusion) have also been found to be important in the development of OSA[6]. Visual inspection of the nose and pharynx can rule out major anatomical obstructions and malignancies. Physical examination includes evaluation of facial morphology, oral cavity and oropharynx.

Nasal examination

The nasal examination includes an anterior rhinoscopy using a speculum with the patient seated with the head slightly back. This allows the detection of septal deviation, turbinate hypertrophy, nasal polyps and other masses, and the internal nasal pathway.

According to the literature, some of these characteristics are related to OSA[7-9]. Friedman *et al*[7] found that three parameters of physical examination predict OSA: modified Malampatti, tonsil size, and body mass index. Zonato *et al*[8] also found that in combination with BMI, pharyngeal anatomic abnormalities and the grade of the modified Mallampati were related to the presence and severity of OSA.

Other relevant studies addressing physical findings and risk for OSA (defined by a respiratory disturbance index greater than or equal to 15) showed that UA narrowing by the lateral pharyngeal walls had the highest association with OSA[10]. UA narrowing was followed by tonsillar enlargement, uvular enlargement and tongue enlargement.

Nasopharyngoscopy: Nasopharyngoscopy is performed while the patient is awake, similar to the physical examination, when muscle tone and respiratory drive are different than during sleep. Anatomic abnormalities can be detected, including hypertrophy of the tongue, uvula, and tonsils, as well as oedema of the soft palate and uvula. Anatomical narrowing are best evaluated with the patient in the supine position; however, this assessment is generally performed with the patient in a sitting position. The Muller manoeuvre is associated with nasopharyngoscopy in order to better assess the maximum level of pharynx narrowing. Several aspects of this technique are controversial, in terms of whether the patient should be in a seated position or supine and whether the patient should stay awake or asleep; and the variable intensity of negative respiratory effort during the manoeuvre.

Measures of upper airway collapsibility

The most frequently described methods of evaluating upper airway collapsibility are the critical pressure measurement (Pcrit) and the negative expiratory pressure (NEP) technique.

Pharyngeal critical pressure (Pcrit): The critical pressure, or Pcrit, is the pressure at which maximal inspiratory airflow occurs during sleep. The Pcrit is based on the relationship of pressure and flow through a collapsible tube (Starling resistor).

Occlusion occurs when the Pcrit becomes greater than the intraluminal pressure, resulting in a transmural pressure of zero. This model was suggested to describe the pharyngeal airway as a collapsible tube[5]. Gold & Schwartz[5] demonstrated that the Pcrit can be estimated using nasal continuous positive airway pressure (CPAP). Even though the Pcrit determination requires a quantitative measurement of flow and inspiratory effort, an approximation of the Pcrit can be simply measured during the study of the nasal CPAP by monitoring the nasal pressure. When the nasal pressure is below the Pcrit, the pharyngeal airway is occluded, and there is no fluctuation of mask pressure with respiration. When the nasal pressure is raised above the Pcrit and respiratory airflow begins, the mask pressure fluctuates with respiration. To measure the Pcrit, the nasal pressure is raised in 1-2 cm H_2O increments during stage 2 sleep. The Pcrit of the airway is established between the last nasal pressure at which the mask pressure does not fluctuate with respiration and the first nasal pressure at which the fluctuation is apparent.

Measurements of Pcrit airway obstruction are classified as follows: (*i*) Pcrit < -10 cm H_2O are considered normal breathing, (*ii*) Pcrit from -10 to -5 cm H_2O are classified as snoring, (*iii*) Pcrit from -5 to 0 cm H_2O are classified as obstructive hypopnoeas, and (*iv*) Pcrit > 0 cm H_2O during sleep are considered obstructive apnoeas. Patients with upper airway resistance syndrome (UARS), an entity characterized by flow-limited breathing that results in the disruption of sleep, typically have Pcrit levels between snoring and hypopnoea[10].

Negative expiratory pressure (NEP) technique: Recently, the negative expiratory pressure (NEP) method has been introduced to detect an intrathoracic expiratory flow limitation in humans, under different conditions. The NEP consists of the application of negative pressure (usually between -3 and -5 cm H_2O) during tidal expiration, thus increasing the pressure difference between the alveoli and the airway opening. In the absence of flow limitation, there is an increase in the expiratory flow. In the presence of flow limitation, the expiratory flow does not increase at any point in the tidal expiration, compared to the flow of the preceding control expiration[11].

In normal, awake subjects, the transient application of a small NEP at the onset of resting expiration does not elicit a reflex of the genioglossus or a change in the upper airway resistance[12,13].

Acoustic reflection

Jackson *et al*[14] and Fredberg *et al*[15] first described the use of an acoustic reflection switch that relies on the fact that sound is reflected by changes in impedance caused by changes in the pharyngeal cross-sectional areas. Acoustic reflection performed through the mouth are highly correlated with roentgenographic area. When used on the nose, this technique is termed acoustic rhinometry and does not provide information regarding the pharyngeal cross section. This method requires a fixed position of the head and neck and becomes uncomfortable for sleeping patients. However, when this technique is used with a flexible tube placed in the nose, pharynx and oesophagus, it becomes possible to assess the narrowing of the upper airway during sleep.

The flextube recording is accompanied by minimal discomfort in the absence of relevant complications, it is easy to perform, and it can be combined with PSG. The flextube device, in contrast to the pressure catheter, provides information regarding the length of obstruction during the entire respiratory event. However, it is relatively invasive and can disturb sleep.

Cephalometric radiograms

Although the pharynx is a three-dimensional structure and patients are usually evaluated wake and during upright position, lateral cephalometry is commonly used in clinical practice because of its relative simplicity, accessibility, low cost and minimal radiation[16].

Cephalometry provides a lateral radiographic view of the head and neck in a standard plane with specific emphasis on bone and soft tissue landmarks (Fig. 1). This technique reveals a variety of soft and hard tissue abnormalities that may indicate patients with narrow and collapsible upper airways. Cephalometry has provided substantial insight into the pathophysiology of OSA, identifying the most significant craniofacial characteristics associated with this disease. Although the cephalometry results are not easily comparable, the specific cephalometric characteristics have been

Fig. 1. Lateral cephalometry in patient with OSA – Note a steep mandibular plane, a narrow posterior airway space, an increased length and width of the soft palate, and an inferiorly positioned hyoid bone.

mentioned repeatedly as risk factors for OSA. Patients with OSA often have a posteriorly placed mandible, a narrow posterior airway space, enlarged tongue and soft palate, and an inferiorly positioned hyoid bone[17,18] (Fig. 2). In a recent investigation, Hou *et al*[19] reported more prominent abnormalities in craniofacial morphology in patients with severe compared to less severe OSA. The mandibular body length, craniofacial extension, and hyoid position were especially predictive variables for night apnoea hypopnoea index (AHI). Other research groups have confirmed that certain anatomic variables were more prevalent in OSA patients and also predictive of disease severity[20,21].

Some studies suggest that obesity and neck size are more powerful predictors of OSA severity than cephalometric variables. Davies & Stradling[22] studied the predictive value of neck circumference, obesity, and cephalometric variables. Although body mass index, hyoid position, and palate length correlated with apnoea severity in a single regression analysis, only neck size and retroglossal space were significantly and independently associated with apnoea severity.

Lateral X-ray cephalometry has also been evaluated as a tool to predict the postoperative results of uvulopalatopharyngoplasty (UPPP), either alone or in combination with other approaches[23], being considered a standard test in the preoperative evaluation of the craniofacial skeletal anatomy before maxillomandibular advancement surgery[24]; however, the predictive value of X-ray cephalometry for UPPP remains questionable[25].

Computerized tomography (CT)

The majority of studies using CT to investigate OSA were published from 1980-1990. Sagittal or cross-sectional images of the retropalatal and retrolingual regions[26,27] were obtained to determine the sites of narrowing, as well as the width of the tongue and UA muscle. Cine CT or ultra-fast CT have been used to obtain multiple images with a lower radiation exposure than standard CT[28-30]. Due to the limitations of CT in comparison with MRI, particularly its poor resolution in detection of airway fat, it is not frequently used for UA evaluation of OSA patients.

Magnetic resonance imaging (MRI)

MRI often detects a lateral narrowing in OSA patients. As a consequence of this narrowing, the major axis is abnormally oriented in the anterior-posterior dimension – a feature that could increase airway collapsibility[2,31,32]. However, there is some controversy regarding the specific determinants of these abnormalities, especially in obese patients. For instance, some authors have demonstrated that the pattern and volume of local fat deposition are closely related to OSAS[33-35], while others have found that parapharyngeal muscle hypertrophy and/or enlargement of non adipose

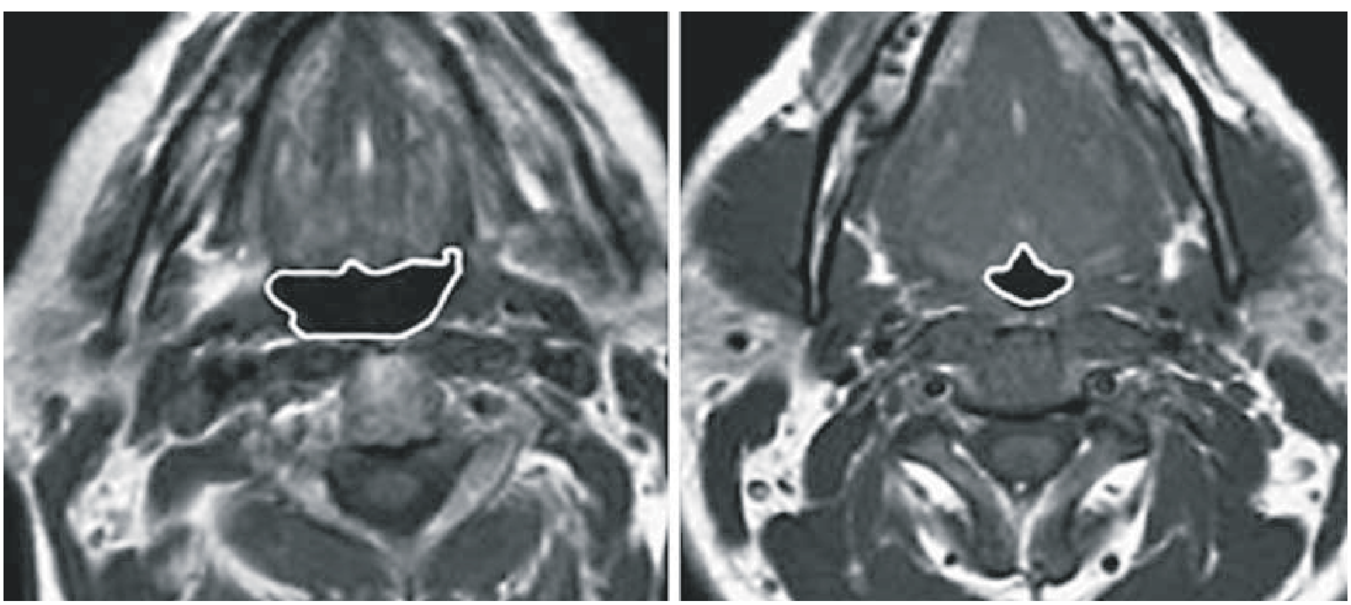

Fig. 2. Axial T1-weighted spin-echo images of the pharynx at the retroglossal level in an obese control (left) and a patient with OSA (right): note the increase in the anterior-posterior diameter with evidence of lateral narrowing (reduction of transversal diameter of pharynx air column) in patient with OSA. [*Source* : Ref. 32. Reprinted with permission].

soft tissues are more frequent in OSAS patients than controls[36]. These discrepancies may be related to the comparison between obese versus non obese subjects; our previous study[32] addressed these aspects within the obese group.

In a previous study, we hypothesized[32] that obese subjects with OSA would present with distinguishable upper airway anatomical characteristics, allowing a better characterization of obese patients with an increased risk of OSAS. The transverse diameter of the airway at the retroglossal level was lower in these patients, as measured by MRI, and the lateral pharyngeal muscles were thicker than the controls. This measure independently predicted the presence and severity of OSAS. A transverse diameter of UA > 12 mm was especially useful to rule out severe OSAS (AHI > 30). Parapharyngeal fat increase, however, was not related to OSAS.

While most studies have examined the UA in two dimensions, measuring the distances and cross - sectional areas of the UA structures, the three-dimensional assessment of UA using MRI has recently been shown to be more accurate than bi-dimensional assessments[31,37]. In a case-control study, Welch *et al*[37] employed a sophisticated volumetric analysis using MRI to detect enlarged soft tissue structures surrounding UA in patients with OSA compared to controls. They also demonstrated a significantly increased risk of sleep apnoea; after covariate adjustments; associated to a larger volume of the tongue, lateral pharyngeal wall and soft tissue . The volume of the tongue and lateral walls independently increased the risk of sleep apnoea in a multivariable logistic regression analysis.

Dynamic MRI has also been used to evaluate UA during sleep only for research purposes in order to explain the physiopathology of UA constriction. Ikeda *et al* [38] showed that spontaneous sleep causes significant obstruction and a narrowing of the various sites of the pharyngeal airway in a case-control study. OSA patients demonstrated a significant decrease in both mean values of the cross-sectional area and AP diameter of the soft palate in comparison to non OSA subjects.

Genetics vs. images

It has been proposed that anatomic risk factors for OSA are mediated by genetic factors[39,40]. Schawb *et al*[40] studying OSA subjects and their siblings compared to controls and their siblings using volumetric MRI demonstrated that volume of the lateral pharyngeal walls, tongue, and total soft tissue were significantly heritable after adjustment for sex, ethnicity, age, visceral neck fat, and craniofacial dimensions. These data indicate that the size of upper airway soft tissue structures has a family aggregation pattern.

Conclusion

The evaluation of the upper airway includes the physical examination of pharyngeal structures and a number of imaging techniques that vary from the mostly used lateral cephalometry to tri-dimensional MRI.

This evaluation has contributed to understand the pathophysiology and the diagnosis of OSA and snoring. Additionally, it helps to identify the subjects with increased OSA risk as well as to select the more appropriate modality of treatment, especially for surgical procedures. In general, in clinical practice only simple imaging techniques have been utilised, however, the imaging techniques of high complexity provide further information about anatomy and function of upper airway, leading to more appropriate management of this prevalent respiratory sleep disorder.

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