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Review Article

Upper airway imaging techniques for obstructive sleep apnea syndrome

Seema Shantilal Pendharkar[1]*, Sakshi Jain[1], Harshad Bhagwat[2]

[1]*Dept. of Oral and Maxillofacial Surgery, CSMSS Dental College and Hospital, Chhatrapati Sambhajinagar, Maharashtra, India*
[2]*Dept. of Oral and Maxillofacial Surgery, Guru Gobind Singh College of Dental Sciences, Burhanpur, Madhya Pradesh, India*

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ABSTRACT

Obstructive sleep apnea syndrome (OSAS) is a sleep disorder marked by recurrent stops in breathing during sleep or by not breathing for 10 seconds or longer despite an effort to breathe. It is brought on by a partial or total blockage of the upper airway, which results in apnea or hypopnea. Soft tissue in the back of the throat collapses and blocks the upper airway when muscles relax while you sleep. The Apnea-Hypopnea Index (AHI) is a widely used metric to quantify sleep apnea. The total number of apneas and hypopneas that happen during an hour of sleep is represented by this average. The majority of people with OSA remain undiagnosed, even with the recent advancements in sleep medicine diagnostic technologies and public awareness of the condition. The upper airway imaging methods for obstructive sleep apnea syndrome will be covered in this review.

1. Introduction

Nearly two decades ago, snoring was more of a joke than a topic worthy of serious research, and obstructive sleep apnea was viewed as a medical oddity with minimal significance. The severe medical disorder known as obstructive sleep apnea syndrome (OSAS) is typified by recurrent partial or total blockage of the upper airway as you sleep.[1] Compared to other sleep disorders, OSAS has the highest rates of morbidity and mortality and is the most often assessed condition at sleep disorder centers. Hypertension, coronary artery disease, myocardial infarction, and congestive heart failure are all linked to OSAS.[2] Additionally, OSAS can cause major health issues right away, like excessive daytime sleepiness (EDS), which can affect alertness and cognitive function.[3] The seven-fold increased likelihood of car accidents involving people with OSAS is an often-cited example of the possible short-term effects of the EDS linked to sleep apnea.[4] In comparison to normal controls, people with moderate to severe sleep apnea syndrome had a 15-fold higher risk of motor vehicle accidents, according to a recent replication study of sleepiness-related accidents in sleep apnea patients.[5]

Repetitive, partial, or whole collapse of the upper airway during sleep is the hallmark of obstructive sleep apnea (OSA), a common disorder closely linked to the global obesity pandemic that impairs gaseous exchange and disrupts sleep.

Numerous epidemiological studies have demonstrated that it is the most prevalent type of sleep disordered breathing (SDB) in the globe. Although much of the causal role and mechanisms are still unclear, there is growing evidence that OSA is an independent risk factor for an unfavourable cardiometabolic profile.[6] and has been linked to increased cardiovascular and cerebrovascular morbidity and death.[7]

* *Corresponding author.*
E-mail address: dr.seemapendharkar@gmail.com (S. S. Pendharkar).

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The underlying pathophysiologic mechanisms in SDB involve the interplay of multiple metabolic risk variables, and the proposed relationship between OSA and cardiovascular disease is intricate. Significant additional health effects of OSA include excessive daytime sleepiness, cognitive dysfunction, poor work performance, anxiety, problems in interpersonal relationships, and a higher risk of both fatal and non-fatal car accidents, which result in a significant financial burden and loss of life in our contemporary society.[8]

The majority of people with OSA remain undiagnosed, even with the recent advancements in sleep medicine diagnostic technologies and public awareness of the condition.[9] When the total number of apneic and apneic plus hypopnea episodes is divided by the total amount of sleep in hours, the apneic index (AI) and the apnea-hypopnea index (AHI) are calculated. The AHI and AI have both been employed as indicators of the severity of the condition. The respiratory disruption index (RDI), which incorporates less obvious respiratory episodes including respiratory effort-related arousals (RERAs) in addition to apnea and hypopneas, is another often used index.

An increase in respiratory effort lasting ten seconds or longer that causes arousal from sleep but does not fit the criteria for either apnea or hypopnea is known as a RERA event. The subjective Epworth Sleepiness Scale (ESS) measures a patient's propensity to nod off in particular uninspiring circumstances.[10]

The American Academy of Sleep Medicine states that a diagnosis of OSAS can be made if there are five or more episodes of apnea or hypopnea per hour of sleep, along with clinical symptoms (like mood disorders, insomnia, hypertension, or daytime sleepiness), or if there are at least 15 episodes per hour without any additional symptoms. OSAS is classified as mild if there are five to fifteen occurrences per hour, moderate if there are up to thirty events per hour, and severe if there are more than thirty.[11]

2. History

In his Posthumous Papers of the Pickwick Club, Charles Dickens described in great detail the chubby lad Joe who was a noisy snorer and had somnolence, which is quite similar to many of the patients who are referred today for an OSA evaluation. The earliest documented accounts of OSA from the standpoint of contemporary medicine come from the latter part of the 1800s.[12] Broadbent published the first description of what was likely mixed sleep apnea in 1877, according to Lavie. Caton presented a case of narcolepsy in 1889, which was probably a case of sleep-disordered breathing. Later that year, Morison described another case that was similar to Caton's.

Then, in 1889, Heath (using a term from Charles Dickens) came up with the term "Pickwickian" to refer to the obese patient who had trouble breathing while sleeping, which Caton had introduced earlier that year.[13] In the first half of the 20th century, obstructive sleep disordered breathing appears to have been largely ignored. The first polysomnographic recording was created in 1965 by Gastaut et al.[14] to objectively demonstrate the incidence of recurrent apneas during sleep in patients known as Pickwickian.By using cineradiography, Schwartz and Escande[15] shown in 1967 that the upper airway was the location of the apneas.

3. Imaging Techniques

Computed tomography (CT), magnetic resonance imaging (MRI), cephalometric, and nasopharyngoscopy are the main upper airway imaging techniques. The effects of surgery, dental appliances, weight reduction, and respiration on the upper airway have all been investigated using these imaging modalities. The airway and associated soft tissue structures can be quantified in three dimensions using MRI and CT.[16]

Sleeping fibre optic endoscopy has been used as a successful technique to identify the obstruction site in recent years. However, this can also interfere with regular sleep, and examinees may refuse to do so. Nocturnal endoscopy is not a common procedure in the majority of sleep centres. High-speed CT is the best method for identifying the obstructed site because the majority of patients prefer radiological tests.[17] There are currently new imaging methods that use computer fluid dynamics (CFD) to assess the upper airway in OSAS and perhaps forecast therapy measures. The most potent computers are being used in this extremely intricate bioengineering procedure.[18]

4. Nasopharyngoscopy

Endoscopic pharyngoscopy is the most effective method for evaluating the nasal, oral, and hypopharynx. Upper airway examination aims to detect the classic sites and reasons of obstruction, such as cancer, radiation fibrosis, tonsils, ectopic thyroids, and vocal cord paralysis.[19] Endoscopy can readily assess the airway's morphology at different points. A transverse airway that is reduced in the anterior-posterior dimension will result from the mandible and tongue being positioned retro. In addition to causing OSAS, nasal obstruction can raise negative pharyngeal pressure, which can result in obstruction and collapse.[20]

An epiglottic collapse was discovered during the Mueller maneuver in 11.5% of uvulopalatopharyngoplasty (UPPP) failures, according to Catalfumo and colleagues.[21] Individuals with OSAS were evaluated preoperatively using fibreoptic nasopharyngoscopy with Muller maneuver (FNMM) to determine which individuals had the most pharyngeal collapse in the tonsillar fossae and soft palate region.

Patients who received UPPP because they were thought to have the best chance of responding to surgery had

pharyngeal alterations on FNMM, according to Sher and colleagues.[22] Most people can mimic snoozing and apnea, and the Mueller maneuver can have a direct impact on wakefulness. Therefore, snoring simulation and the Mueller maneuver's effects have been utilized to evaluate a patient's upper airway before to surgery in order to improve patient selection and predict surgical prognosis.

5. Cephalometric Radiography

A straightforward, affordable, easily available, and useful screening technique is cephalometric assessment. It offers longitudinal comparison across populations and time. Cephalometric radiography has shown important craniofacial features linked to OSA, offering valuable insights into the disease's aetiology. Certain cephalometric features such as a thick and lengthy soft palate, a retro location of the maxilla or mandible, and particularly the more inferiorly positioned hyoid bone have been identified time and time again as risk factors for OSA, despite the fact that the data are difficult to compare.[23]

It can also be used to measure how patients' airways change before and after treatment. OMS and orthodontists have easy access to cephalometric analysis. Patients with OSAS had a smaller cranial base flexure angle and a shorter cranial base, according to cephalometric research. Patients with sleep apnea often have a cranial base flexure angle of 122º (normal, 129º) and a cranial base length of 76.5 mm (normal, 83.3 mm).[24]

However, the best way to assess the pharyngeal air space is not with cephalometric radiographs. Some patients with severe apnea seem to have adequate posterior airway spaces and normal cephalometric measurements. Cephalometry has the drawbacks of being static and just two-dimensional. The amount of MMA required to produce the required alteration in the posterior airway space cannot yet be determined.[25]

6. Computed Tomography

Soft tissue contrast is much enhanced by CT scanning, which also enables volumetric evaluation, three-dimensional reconstruction, and accurate measurements of cross-sectional areas at various levels. Three-dimensional CT scans are useful for giving the surgeon anatomical information that is pertinent to planning upper airway surgery and tracking its results, according to Li and colleagues.[26] Patients with apnea have a different upper airway geometry and diameter than healthy ones. The apneic airway narrows laterally and is smaller. A normal person's upper airway volume fluctuated slightly during the expiration and inspiration periods of sleep, ranging from 9.2 cm3 to 11.56 cm3. In a habitual snorer, it varied moderately between 3.74 cm3 and 9.91 cm3, and sharply between 2.73 cm3 and 16.01 cm3 in an OSAS patient.

The pathophysiology of OSAS is believed to involve anatomic abnormalities of the pharynx.[27] The most important upper airway three-dimensional CT scan parameter found in patients with sleep disorders is the retropalatal space, which is strongly linked to a compromised airway diameter. The decrease in the apnea hypopnea-index (AHI) observed in postoperative polysomnographic investigations is believed to be caused in part by this. The muscles, ligaments, and tendons are passively tightened during jaw surgery as their bony origins advance rather than being removed. The lingual and suprahyoid muscles, as well as the pharyngeal and palatal muscles, are altered as a result. The pharyngeal soft tissue tube enlarges in tandem with skeletal expansion. The mechanical expansion of the posterior airway area and a shift in the tension in the velopharyngeal and suprahyoid muscles are probably what make mixed martial arts (MMA) so effective. The palate's soft tissue is drawn upward and forward by the maxilla's advancement. Additionally, it improves tongue support by drawing the palatoglossal muscles forward.

7. Magmetic Resonance Imaging

MRI has several benefits over CT scanning or lateral radiography cephalometry, including superior soft tissue contrast, three-dimensional evaluations of tissue architecture, and the absence of ionized radiation. MRI is the preferred imaging method for evaluating children with sleep-disordered breathing (SDB) due to its benefits, including its lack of ionizing radiation. Using MRI, Schwab and colleagues[28] examined the soft tissue structures surrounding the upper airway in 26 OSAS patients, 21 snorers/mild apneic participants, and 21 normal subjects. They found that the main anatomic component driving airway narrowing in patients with sleep apnea was the thickness of the lateral pharyngeal muscle walls, not the growth of the parapharyngeal fat pads, at minimum airway area.

Apneic participants did not have larger fat pads at the level of the minimal airway than healthy subjects. Dynamic MRI may help with treatment by detecting the degree of blockage during sleep and the severity of OSAS, according to Shintani and colleagues.[29] Furthermore, they discovered a strong correlation between the breadth of the airway gap between the base of the tongue and hypopharynx and the severity of AHI and oxygen saturation (SpO2). Isono and colleagues[30] discovered that the passive pharynx is more collapsible and narrower in sleep apnea patients compared to matched controls based on statistical pressure area connections. This aligns with the findings of the previous research.

The mandible's retro position will permit the tongue to press on the pharyngeal airway, reducing airflow as you sleep. There is a substantial correlation between the

breadth of the airway gap at the base of the tongue and hypopharynx and the severity of AHI and SpO2.[29] An effective non-invasive technique for assessing OSA is ultrafast MRI. Functional ultrafast MRI can identify the location of pharyngeal narrowing and occlusion in awake patients, as demonstrated by the strong correlation between the results from dynamic MRI and trans nasal fibreoptic endoscopy.[31]

8. Echo Imaging, Acoustic Reflection Technology

The usage of an acoustic reflection switch, which is based on the idea that sound is reflected by changes in impedance brought on by variations in the pharyngeal cross-sectional areas, was initially described by Jackson et al.[32] and Fredberg et al.[33] A approach to evaluate the patient's airway is through acoustic reflection. Via a separate central processing unit made up of the rhino meter and pharyngometer, it produces sound waves. The patient's pharyngeal airway and nasal airways are mapped by them, respectively. A non-invasive method called acoustic reflection analyses a sound wave that has been reflected from the respiratory system. The upper airway area may be calculated as a function of distance from the mouth thanks to acoustic reflectance. Anatomical details about distinct structures cannot be obtained from acoustic reflection. Because the mouth is closed during imaging, upper airway area calculations made using acoustic reflection may not be comparable to those made using other imaging modalities. Pharyngeal size has been compared between snorers, non-snorers, and OSAS patients using acoustic reflection. Its benefits include speed and non-invasiveness, as well as the ability to continuously assess the patency of these areas. However, there are two main limitations to the technique: it cannot be utilized while you are sleeping, and it cannot evaluate the nasopharynx.[34]

9. Fluoroscopy

The dynamic function of the airway and the degree of blockage or stenosis during sleep are both revealed by fluoroscopy. The most common site of upper airway collapse is the velopharynx.[35] Following initial velopharyngeal obstruction, oropharyngeal blockage may also develop; this is typically facilitated by elevated negative inspiratory pressure. When assessing OSA, dynamic sleep fluoroscopy is a helpful supplement to endoscopy. Results from sedative-assisted dynamic sleep fluoroscopy have been demonstrated to influence therapy choices in over 50% of patients. Despite the upper airway's intricate architecture, only transverse pictures can be acquired. The measurement of airway size may be impacted by the partial volume effect.[36]

The dynamic alterations of the upper airways during the respiratory cycle are illustrated by Tsushima and associates.[37] Only the anterior-posterior dimensions may be seen using digital fluoroscopy, which only offers a two-dimensional lateral perspective. In contrast to normal persons, who have a horizontal arrangement with the primary axis in the lateral orientation, apnea patients have an anterior–posterior airway. Digital fluoroscopy's lateral view is unable to display this alteration in upper airway morphology. Perhaps just as significant as the anteroposterior dimension of the upper airway is the lateral dimension.

10. Computer Fluid Dynamics

Researchers have started to measure the volumes of soft tissue structures such the tongue, adenoids, soft palate, pharyngeal walls, and the remaining compromised or non-compromised airway spaces in addition to basic two-dimensional evaluation. Slice thickness is determined using a variety of computational models, and volumes are computed on cross-sectional areas to produce three-dimensional data. Computer-aided engineering (CAE) has developed into a mature technology that is used extensively in the engineering community for design, analysis, and performance forecasting after several decades of computer development. As the performance-to-cost ratio of computer hardware has increased over the last 20 years, the development has gained particular significance. The computational engineers now have access to processing power that was unthinkable ten years ago.

The scientific fields of numerical geometry modelling, numerical mesh generation, scientific visualization, virtual environment technology, and high-performance parallel computing are among the enabling technologies related to computer fluid dynamics. They make it possible for simulation fields like computational structure mechanics (CSM) and computer fluid dynamics (CFD), which solve the governing equations through numerical techniques to produce high-fidelity computational simulations of fluid flow transport processes and structural behaviours. Medical communities can gain a better grasp of the hemodynamic and airflow of human biologic systems by using such computational tools.[38,39]

Creating high-quality numerical meshes from CT images while preserving geometry accuracy is the first step in enabling these computational technologies. The cubic spline, Hermit spline, Bezier spline, and B-spline are only a handful of the numerical geometry methods that have been introduced in recent decades. The nonuniform rational B-spline is the de facto industry standard for the modelling and creation of geometry algorithms, and it has become quite popular in the CAE community.[40]

11. Polysomnography

PSG assesses oxygen desaturations, sleep architecture, and breathing disorders. Multiple channels of physiological parameters, such as electroencephalogram, electrooculography, chin and leg movements via electromyography, ECG, heart rate, respiratory effort, chest and abdominal wall movements, airflow, and oxygen saturations, are measured during a standard 8-hour nocturnal laboratory PSG. A sleep technologist records body posture while scoring various physiological indicators.[41]

After analysing the test results and score information, a board-certified sleep medicine specialist issues a report that addresses the OSA diagnosis. The AHI, or the number of apneas and hypopneas per hour of sleep, is the main indicator of sleep-disordered breathing. An airflow disruption of at least 10 seconds in adults or the equivalent of two breaths in children is referred to as an apnea.[42] A hypopnea is defined as a specific decrease in airflow accompanied by an oxygen desaturation or arousal that lasts for at least 10 seconds in adults or two breaths in children. The main metric for assessing the severity of OSA and the efficacy of treatment is the AHI. Mild (AHI 5–15), moderate (AHI 15–30), and severe (AHI R 30) are the three classifications.[43]

CPAP therapy can be started if apnea is detected during the diagnostic PSG (AHI of 40 within the first two hours). The initial diagnostic PSG and the CPAP titration during PSG on the same night are referred to as a split-night study. Only when CPAP titration lasts more than three hours and produces a PSG parameter document showing that CPAP almost completely eliminates the respiratory episodes during REM and non-REM sleep, including while the patient is in a supine posture, is a split-night study permitted.[44]

12. Discussion

Twenty years ago, Young and colleagues[45] published the first prevalence report on sleep-disordered breathing, which was based on the Wisconsin Cohort Study (WSCS). Higher prevalence estimates were reported in a WSCS follow-up. However, because the previous study included a panel of individuals at risk for sleep-disordered breathing, it was not strictly population-based. Therefore, models extending the observed results to the overall US population using demographic data from the National Health and Nutrition Examination Survey (NHANES) research were used to determine the reported prevalence of sleep-disordered breathing. There have only been two studies conducted thus far that are directly based on samples drawn from the general community.[46,47] Researchers found a high prevalence of sleep-disordered breathing in both investigations. The prevalence of sleep-disordered breathing (apnea-hypopnea index >5 occurrences per hour) was 26·2% in males and 28·0% in women in a Spanish study involving 2148 people between the ages of 30 and 70. The majority of individuals were examined using limited channel recorders without direct airflow monitoring, which is not in accordance with current norms, and only a subgroup of 390 participants received full polysomnography. The most recent breathing sensors were used to detect nasal pressure variation in a Brazilian study with 1042 individuals ranging in age from 20 to 80 years. This method is routinely employed in all contemporary clinical laboratories.

The researchers found that 30·5% of women and 46·6% of males had sleep-disordered breathing (apnoea-hypopnoea index >5 occurrences per hour); however, these findings were acquired in a particular mixed ethnic group and are not easily generalizable to other populations.

13. Conclusion

Apneic patients' upper airway dimensions and configuration, especially during sleep, differed from those of healthy participants (i.e., a more circular shape and a smaller minimum area of the velopharynx). This implies that the velopharynx, which tends to obstruct the upper airway, is more collapsible in apneic patients. The inverse link between the airway area and the lateral pharyngeal wall dimensions most likely suggests that alterations in the airway lumen cause the lateral walls to become passively restricted or stiffened. In individuals with obstructive sleep apnea, magnetic resonance imaging investigations may help understand the processes of apnoea, particularly when ultrafast techniques are applied while the patient is asleep.

CT and particularly MRI have become crucial auxiliary techniques in the clinical diagnosis, preoperative assessment, and post-treatment monitoring of patients who do not respond well to early therapy, even if polysomnography is the approach used to confirm the diagnosis of OSA. Better clinical evaluation and planning for a potential surgical approach are made feasible by the excellent evaluation of the site of obstruction's multiple anatomical planes that both CT and MRI may provide.

14. Source of Funding

None

15. Conflict of Interest

None

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Author's biography

Seema Shantilal Pendharkar, Associate Professor
https://orcid.org/0000-0002-7816-9442

Sakshi Jain, PG Student

Harshad Bhagwat, Professor and HOD

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