Imaging the obstructed Airway:

Introduction:

The structure and the neural control of the upper airway have evolved to serve four important physiological functions: 1) respiration 2) deglutition 3) speech and 4) local immunity. The upper airway is collapsible in order to accommodate these functions. During wakefulness, upper airway collapse can be prevented by an increase in pharyngeal neuromuscular tone (1). However, this mechanism is decreased during sleep, predisposing the upper airway to obstruction (2).

The obstructive sleep apnea syndrome (OSAS) refers to a breathing disorder characterized by recurrent, partial or complete episodes of upper airway obstruction, commonly associated with intermittent hypoxemia and sleep fragmentation (3). OSAS affects individuals of all ages, from neonates to the elderly. However, it is still not known whether OSAS represents a continuum of a disorder that places pediatric patients at risk for the disease as adults (4), or whether OSAS during different stages of life comprises distinct clinical entities (5-8).

The anatomic factors predisposing to OSAS differ over the lifespan. However, a smaller upper airway is noted in patients with OSAS in all age groups, and probably predisposes to airway collapse during sleep. Despite the known anatomic factors, such as craniofacial anomalies, obesity, and adenotonsillar hypertrophy, that contribute to OSAS throughout life, a clear anatomic factor cannot always be identified. This suggests that alterations in upper airway neuromotor tone also play an important role in the etiology of OSAS. The present chapter will focus on the known anatomic risk factors leading to OSAS during child development, with emphasis on studies using magnetic resonance imaging (MRI) that provide the most quantitative and reproducible data.

In preschool children, the incidence of OSAS is estimated to be 2% (9, 10), whereas primary snoring is more common and is estimated as 6-9% in school-aged children (11). Although the exact mechanism for OSAS in children is not fully understood, important anatomic risk factors have been identified, and are linked to the anatomical structures surrounding the airway that affect the size and shape of the airway.

The Waldeyer's ring, which is the lymphoid immunocompetent tissue within the upper airway, is comprised of the pharyngeal tonsil or adenoid, the paired palatine tonsils, and the lingual tonsil. These tend to enlarge during childhood in response to somatic growth (12-14) and are a potential focus for infection and inflamation (15). Therefore, in this age group, in the absence of obesity and when no apparent craniofacial anomalies or neurological disorders exist, adenotonsillar hypertrophy is considered the most significant anatomic risk factor for OSAS.

Imaging of the Upper Airway:

Physical examination of the upper airway of the child is important and should be performed in each child as part of the general assessment. However, in order to more thoroughly evaluate the airway, endoscopy (16) and imaging techniques such as lateral neck radiographs, cephalometrics, fluoroscopy, acoustic reflection, computerized tomography and MRI are available (17-22). The above modalities have all demonstrated that the upper airway of children with OSAS is smaller on average than that of the normal child.

MRI is a particular powerful tool because: 1) it provides excellent upper airway and soft tissue resolution; 2) it provides accurate, reproducible quantification of the upper airway and surrounding soft tissue structure; 3) imaging can be performed in the axial, sagittal and coronal planes; 4) volumetric data analysis including three-dimensional reconstructions of upper airway

soft tissue and craniofacial structures can be performed (23) 5); dynamic images provide 4-dimensional data of the size and shape of the airway during breathing (Figure 3); and 6) it does not expose subjects to ionized radiation. On the other hand several limitations should be noted: 1) young children need to be sedated to avoid motion artifact; 2) studies can not be performed in sleep conditions in the MRI environment because of noise, arousals, and movement artifact 3) it is expensive and not always available.

Airway Size:

Using MRI, Arens et al. (17) studied the upper airway in 18 children with moderate OSAS (age 4.8 ± 2.1 years) with an apnea/hypopnea index of 11.2 ± 6.8, and compared these findings to 18 matched controls. MRI was performed under sedation, and axial and sagittal T1 and T2-weighted sequences were obtained. The volume of the upper airway was smaller in subjects with OSAS in comparison to controls (1.5 ± 0.8 cm^3 vs. 2.5 ± 1.2 cm^3, $p<0.005$). This finding was later reproduced by other investigators (24, 25) using similar techniques.

Airway Architecture:

In order to determine the anatomic region of maximal narrowing in children with OSAS, Isono *et al* performed upper airway endoscopy under general anesthesia, evaluating discrete levels of the upper airway including the adenoid, soft palate, tonsil, and tongue (16) (see chapter 8). The minimum cross-sectional area was found to be at the level of the adenoid and the soft palate. These findings, along with high closing pressures noted at these points in the same study, suggest that the superior upper airway segments are most involved in children with OSAS. These findings are supported by two recent studies evaluating upper airway size with MRI. Arens *et al* (26) showed that airway narrowing in children with OSAS occurred along the upper two thirds of the airway, and was maximal in the region where the adenoid overlapped the tonsils (Figure 4). Similar findings were noted by Fregosi *et al* (25), who described maximal narrowing in the retropalatal region where the soft palate, adenoid, and tonsils overlap.

Airway Dynamics Depicted by MRI:

More recently, Arens et al. used respiratory-gated MRI to demonstrate the kinematics of the upper airway during tidal breathing in children with OSAS (27). They showed that the maximum restriction in patients with OSAS occurred in mid inspiration, and that dynamic fluctuations in the airway overlap region were 6 fold higher than in controls. They have speculated that such changes may have been induced by one of the following: altered upper airway motor tone, increased airway compliance, or excessive inspiratory driving pressures caused by proximal airway narrowing.

In the above study, shape analysis demonstrated a different configuration of the airway in children with OSAS in both inspiration and expiration as compared with control subjects. Subjects with OSAS exhibited an airway shape narrowed across the A-P axis. This could be caused by anatomic features influencing the width of the lateral pharyngeal wall and/or by neuromotor factors affecting upper airway dilator muscle activity along this axis (i.e., genioglossal activation). These differences, together with the magnitude of area changes during tidal breathing, may contribute to a more collapsible airway in children with OSAS during sleep, as suggested by functional studies (16, 20, 28).

Soft tissues:

Adenoid and Tonsils: Soft tissues, particularly the tonsils and adenoid, can also narrow the pharynx. These tissues grow progressively during childhood (12-14, 29), and are maximal in the prepubertal years (14), coinciding with the peak incidence of childhood OSAS (30). In normal children, the airway size grows proportionately with the soft tissues surrounding it (12).

However, it is not known how the airway grows in proportion to the surrounding tissues in children with OSAS.

Arens *et al* , measured the size of the adenoid and tonsils in children with OSAS compared to controls (17). They noted that both were significantly larger in the OSAS group; 9.9 ± 3.9cm^3 and 9.1 ± 2.9cm^3 vs. 6.4 ± 2.3cm^3 and 5.8 ± 2.2cm^3 ($p<0.005$; $p<0.0005$, respectively). In addition, a significant correlation between the combined size of the adenoid and tonsils and the apnea/hypopnea index was found ($p = 0.03$, $r = 0.51$), suggesting that volumetric measurements of these tissues may be useful in predicting the severity of obstructive sleep apnea in these children.

In most cases, large tonsils and/or adenoid can explain the clinical symptoms of children with OSAS, and surgical removal of these tissues cures or ameliorates the disorder in the majority of cases (31-34). However, it is estimated that in 10-15% of otherwise normal children with OSAS, this disorder is not resolved by the simple removal of the tonsils and adenoid (35-37).

Although the importance of adenoidal and tonsillar hypertrophy in the pathogenesis of childhood OSAS is unquestioned, much remains to be learned. It is possible that the three-dimensional orientation of these tissues, and how they overlap in the airway, is a more important factor, and may significantly affect flow resistance during sleep. This is suggested by recent reports using three-dimensional MRI techniques, showing that maximal airway narrowing occurred in subjects with OSAS along an airway segment where both the adenoid and tonsils overlap (17, 25, 26).

Tongue size: The tongue is one of the largest structures defining the oropharyngeal airway, and bounds its anterior aspect. It is composed of extrinsic muscles (genioglossus, hyoglossus and styloglossus), which alter its position; and intrinsic muscles, which alter its shape; both of which can affect airway size and shape. Arens *et al* found that the overall volume of the tongue in non syndromic children with OSAS did not differ from controls (17).

Soft palate: There are few data on the dimensions of the soft palate in children with OSAS. Using direct measurements, Brodsky *et al* (38) did not find a correlation between soft palate length and severity of tonsillar hypertrophy in children with OSAS. Using MRI, Arens *et al* (17) noted a 30% increase in the volume of the soft palate of children with mild to moderate OSAS compared to controls. They speculated that the larger palatal volume might have been due to edema and inflammatory changes secondary to chronic snoring, as described in adults (39-41).

Craniofacial Structure:

Several studies using cephalometrics support the idea that children without distinct craniofacial anomalies have subtle craniofacial morphometric features associated with OSAS (19, 42-45). Kawashima *et al* (46) reported that children with OSAS and more pronounced tonsillar hypertrophy had retrognathic mandibles and increased posterior facial height compared to children with OSAS and less pronounced tonsillar hypertrophy. Shintani *et al* (42) noted that the relationship of the mandible with respect to the cranial base was retrognathic in children with OSAS compared to normal children. Zucconi *et al* (47) noted that children with OSAS had increased craniomandibular, intermaxillary, goniac, and mandibular plane angles, indicating a hyperdivergent growth pattern (angle between nasion-sella line and mandibular line>38 degrees).

In contrast to the above, other investigators suggested that the craniofacial changes found in children with OSAS are mild, and are reversible following adenotonsillectomy (45, 48, 49). In a recent study evaluating upper airway structure, Arens *et al* noted no significant differences in the size of the mandible and maxilla of children with OSAS *vs.* controls (17). Furthermore, in

a more comprehensive evaluation of the mandible after three-dimensional reconstruction, these authors found no difference in 8 dimensions of the mandible between children with OSAS and controls, suggesting that mandibular size and shape does not play a significant role in the causation of childhood OSAS in nonsyndromic children (50).

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