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Review Article

Upper Airway Characteristics in Different Skeletal Patterns; A Review of Literature

Mohammed Korayem*[1], Waleed Bakhadher[2] and Nuha Malibari[3]

[1]Associate Consultant in Orthodontics, King Abdul-Aziz Hospital, Makkah, Saudi Arabia

[2]Associate Consultant in Orthodontics, Private Practice, Makkah, Saudi Arabia

[3]Specialist in Family Medicine, Ministry of Health, Saudi Arabia

***Corresponding Author:** Mohammed korayem, Associate Consultant in Orthodontics, King Abdul-Aziz Hospital, Makkah, Saudi Arabia.

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Abstract

There is a close relationship between the pharynx and the dentofacial structures. Orthodontists believe that evaluation of soft tissues including facial contours, neuromuscular function, tongue, tonsil, adenoids and nasal polyps should be an integral part of orthodontic diagnosis and treatment planning. The current review provides an overview of upper airway characteristics in different skeletal patterns.

Keywords: Pharyngeal Airway Dimension; Malocclusion and Pharynx

Introduction

There is a close relationship between the pharynx and the dentofacial structures. The mutual interaction between the pharyngeal structures and the skeletal relationship is a subject of interest for the orthodontists and maxillofacial surgeon.

Orthodontists believe that evaluation of soft tissues including facial contours, neuromuscular function, tongue, tonsil, adenoids and nasal polyps should be an integral part of orthodontic diagnosis and treatment planning [1].

The pharynx is a tube-shaped structure formed by muscles and membranes. It is located behind the nasal and oral cavities and the larynx, and cranial to the esophagus, larynx and trachea. It extends from the cranial base to the level of the sixth cervical vertebra and the lower border of the cricoid cartilage. Its length is approximately 12 to 14 centimeters, and it is divided into three parts; nasopharynx, oropharynx and laryngopharynx. The nasopharynx extends from the nasal turbinates to the hard palate. The oropharynx extends from the hard palate to the base of the epiglottis. The laryngopharynx extends from the base of the epiglottis to the larynx [2].

The tongue is in a close relationship with the oropharynx and functions in symbiosis with other pharyngeal structures during respiration and deglutition. The genioglossus muscle was found to be active during inspiratory phase and prevents occlusion of the airway [3]. The soft palate dimensions and relations with the airway space have an important role in swallowing, respiration and phonation [4]. Its dysfunction can be classified as anatomically incompetent (absolute); where the soft palate length is not adequate for velopharyngeal closure, and functionally incompetent (relative); where the soft palate dimensions are normal but dysfunction occurs as a result of insufficient muscular activity, particularly of the levator veli palatini [5].

The hyoid bone is a horseshoe-shaped bone located high in the neck and encircle the larynx above the thyroid cartilage [6]. It is connected to the pharynx, mandible and cranium through muscles and ligaments as part of the oropharyngeal complex [7]. The hyoid bone is unique because it is the only bone which does not have any bony articulations. It is positioned at the level opposite the lower portion of the third and upper portion of the fourth cervical vertebrae. The position of the hyoid bone in a sagittal direction depends on the length of the muscles running from it to the base of the cranium and mandibular symphysis. The position of the hyoid bone is further modified by the pharyngeal infra- and suprahyoid muscles in addition to the gravity acting on the larynx [8]. The hyoid bone has a role in maintaining a patent airway, swallowing, it prevents regurgitation and maintains an upright posture of the head.

Pharyngeal airway anatomy

The pharyngeal airway is an intricate structure. In conjunction with its surrounding structures, it is responsible for the physiologic processes of swallowing, vocalization, and respiration [2] The airway lies posterior to the nasal cavity, oral cavity, and larynx. It begins posterior to the nasal turbinates and extends inferiorly to the esophagus. The superior wall is formed by the body of the sphenoid bone and the basilar part of the occipital bone [2] The nasal turbinates, soft palate, tongue, and glottis make up the anterior border. The posterior wall is formed by the pharyngeal constrictor muscles. The lateral walls contain adipose tissue, lymphoid tissue, and numerous muscles [2].

The airway is subdivided into three anatomical regions: the nasopharynx, oropharynx, and hypopharynx. The nasopharynx is the area between the nasal turbinates and the hard palate. The oropharynx contains two areas: retropalatal (from the hard palate to the tip of the soft palate) and retroglossal (from the tip of the soft palate to the epiglottis). The hypopharynx extends from the epiglottis to the esophagus [2].

Airway analysis

Wildman in 1961 reviewed the studies utilizing the cephalomtric radiography of the pharyngeal area. King measured vertical and horizontal growth changes in the oral and nasal pharynx [9]. The Frankfurt Horizontal plane was the reference line for the measurements. He used the lateral cephalometric radiographs collected for the Broadbent- Bolton Growth Study. Ricketts (1954) suggested that the cranial base angle could play a role in the velopharyngeal competence [10]. He pointed out that as the cranial base angle became more obtuse, the posterior wall and the soft palate would be more separated, thus increasing the possibility of velopharyngeal incompetence. Subtelny (1957) studied the growth of the soft palate in normal persons using serial cephalometric radiographs [11]. The angle of the soft palate from the palatal plane was recorded at various ages. The horizontal growth of the nasopharynx was represented as the change in the distance from the posterior nasal spine to the posterior pharyngeal wall along the palatal plane. The height of the nasopharyngeal space was represented by the distance between the posterior nasal spine and the nasion-basion plane.

Bibby and Preston (1981) found that the anteroposterior length of the pharynx at the level of the first cervical vertebra can be accurately measured by the distance between the most anterior point on the atlas and the posterior nasal spine [7].

McNamara (1984) introduced the "McNamara's line"- The lower pharyngeal width measured from the intersecting point of the posterior border of the tongue and inferior border of the mandible to the closest point on the posterior pharyngeal wall making a line called "McNamara's line" [12]. Fujioka (1979) introduced the adenoid-nasopharyngeal ratio to evaluate the degree of nasopharyngeal obstruction [13]. They found that the factors that determine nasopharyngeal obstruction were the absolute size of the adenoids and the size and shape of the nasopharynx. Stepovich in 1965 described the hyoid plane AS the plane that connects the most anterior superior point on the body of the hyoid bone to the point midway between its two greater horns [6]. The measurements of the pharyngeal area were related to the hyoid plane and the sella-nasion line. He recommended that the hyoid plane is very practical due the common usage of sella-nasion, its simplicity and the stability of the Sella Turcica. However, Bibby and Preston (1981) pointed out that cephalometric studies of the hyoid plane include the use of intracranial sella-nasion line [7]. The large distance between the intracranial reference lines and the hyoid plane makes it insensitive to changes in the structures located between the two planes. This might give misleading readings for the study of specific area. Bibby and Preston (1981) introduced the hyoid triangle to reduce the effects of cranial posture on the position of the hyoid bone [7]. This triangle is formed by the planes that are located between the cervical vertebrae and the mandibular symphysis.

Growth studies

King (1952) in a longitudinal study on pharyngeal growth found that the distance between the hyoid bone and the cervical vertebrae was constant until puberty and the hyoid bone moved forward slightly with further growth [9]. He also found that the depth of the nasopharynx is established in the first or second year of life whereas the growth in the length of the pharynx continues from 3 months to 16 years of age. There was a pre-pubertal growth spurt in females and a post-pubertal spurt in males. He observed that the growth in the spheno-occipital synchondrosis was counteracted by forward growth of the anterior arch of the atlas and the descent of the hard palate and cervical vertebrae from the cranium respectively. The thirty eight percent increase in the height and width led to eighty percent increase in the volume of the nasopharynx. Subtelny and Baker (1956) in growth study of the nasopharynx did not find any significant changes in the nasopharyngeal depth after the age of twelve years [14].

Subtelny (1957) found that at three months of age the soft palate is attached to the hard palate above the anterior tubercle of the Atlas and is close to the cranial base [11]. He measured the length of the soft palate as the distance from the posterior nasal spine to the tip of the uvula. He also found that the growth in length of the soft palate is most rapid during the early years of life until 1 1/2 - 2 years then a plateau until 4-5 years. Growth resumes an upward trend until l7 years with large variability. In the same study, a rapid increase in the soft palate thickness was noted during the first year of life and the maximum thickness was reached at the age of 14-16 years. The author also found that with seceding age, the angle between the hard palate and soft palate became more acute. Durzo and Brodie (1962) found that during the growth period the hyoid bone keeps its relative vertical position [8]. This was due to the increase in height of the cervical vertebrae and the movement of posterior cranial base and mandible away from each other. However, the anteroposterior position of the hyoid bone showed high variation. King (1952) found in their studies that there is a downward and forward movement of the hyoid bone with growth [9]. Pae., *et al*. (2008) found that when all the permanent teeth except the third molars are erupted, the hyoid bone is near and above a line connecting the third vertebra and the most inferior portion of the chin [15]. It was considered a maturational change related to speech and deglutition. However, they indicated that the descent of the hyoid bone could be an early maturational process or a late process related to age.

Pharyngeal dimensions

Martin., *et al*. (2006) found differences between males and females in the adenoidal and airway areas [1]. However, Tsai, (2002) found no sexual dimorphism in the position of the hyoid bone during the deciduous and early permanent dentition. On the other hand, Sosa., *et al*. (1982) found differences between males and females in the size of the postpharyngeal lymphoid tissue [17]. Grauer., *et al*. (2009) emphasized the importance of considering sexual dimorphism when cone beam technology was used; males tend to have larger airways due to the larger head size [18]. They stressed that this would likely affect the results of a research if male and female samples were pooled. Kumar. V., *et al*. [47] concludes that The pharyngeal airway dimensions are subjected to change with different malocclsuion and Narrow pharyngeal airway space is one of the predisposing factors for mouth breathing and obstructive sleep apnoea.

Airway dysfunction

The literature indicated that there was no final conclusion attained in the attempt to establish cause - and - effect relationship between nasal obstruction, craniofacial morphology and occlusal features. Bresolin., *et al.* (1933) assumed that mouth breathing influence the facial form, and considered a predisposing factor to the development of the "long face syndrome" or "adenoid facies" [19]. Ricketts (1968) and Schulhof (1978) described the characteristic of mouth breathing subject [10,20]. It includes increased lower anterior facial height, retrognathic mandible, proclined maxillary incisors, high v-shaped palatal vault, maxillary constriction, flaccid and short upper lip, flaccid perioral musculature and dull appearance due to a constant open-mouth posture. Harvold, (1968) performed an experimental studies on rhesus monkeys. In the first study, an acrylic block was placed to serve as a tactile stimulus to the tongue forcing the mandible to open in a lower position [21]. The experimental animals showed a significant increase in the totalanterior face height than control animals. In the second study Harvold, (1973) blocked the nasal airways of the monkeys with silicone plugs to transform the monkeys into mouth-breathers [22]. After 15 months of oral respiration, the experimental animals showed lowering of the mandible and an increase in face height, forward protrusion of the tongue and dental malocclusion. Adamidis and Spyropoulos (1933) and Behlfelt., *et al*. (1990) found that mouth breathing was correlated with lowered position of the hyoid bone and anterior - inferior postured tongue with significant downward inclination of the mandible [23,24]. On the other hand, according to Emslie., *et al*. (1952), the typical feature of the long face syndrome was the expression of a hereditary pattern (somatotype) and that mouth breathing was unrelated and should not be considered as an etiological factor and that could only be a para-phenomenon [25]. Obstructive sleep apnea (OSA) syndrome is characterized by temporary occlusion of the upper airway several times during the night which may result in hypoxia and sleep fragmentation. Solow., *et al*. (1993) found that the main symptoms were chronic tiredness, day-time somnolence associated with snoring and intellectual deterioration [26]. Lowe., *et al*. (1997) reported a decrease in the upper airway dimension at the velopharyngeal level together with an increase in soft palate and tongue dimensions [27]. Ozbek., *et al*. (1998b) reported a similar observation in addition to a lower hyoid bone in relation to the mandibular plane, smaller nasopharyngeal and larger hypopharyngeal areas [28].

Pae., *et al*. (2008) studied the role of obesity in hyoid bone position. They found that the body mass index of patients is not related statistically to positional changes of the hyoid bone. This explains why not all obese men have OSA. According to ozbek., *et al*. (1998) and Pae and Ferguson (1999) the prime characteristics of OSA are obesity and low hyoid bones [28,29]. Pae and Lowe (1999) used the eigenshape analysis to evaluate the difference in tongue shape between a group of subjects with OSA and asymptomatic subjects [29]. Their data displayed a difference in the tongue shape between the two groups. They linked the tongue shape to the etiology of

OSA. Handler (1985) reported that airway impairment has been associated with syndromes such as Apert's or Crouzon's [30]. Both syndromes were characterized by severe maxillary hypoplasia, which has been suggested as the source of airway obstruction in the affected subjects. Drake., *et al*. (1993) reported that subjects with cleft lip and palate have reduced nasal airway size compared to normal subjects which predisposes them to oral breathing [31].

Effect of head posture

Natural head posture (NHP) is defined as the balanced upright position of the head of a standing or sitting subject by the post-cervical and masticatory - suprahyoid - infrahyoid muscle groups with the eyes directed forward so that the visual axis is parallel to the floor [28]. Shelton and Bosma (1962), Hellsing (1989) and Solow., *et al*. (1993) and reported in their studies that normal mode of breathing was considered very important factor for optimal dentofacial development [26,32,33]. However, if the nasal breathing was impaired or obstructive sleep apnea was affecting an individual, the head posture will change in order to increase the pharyngeal airway dimension. Hellsing., *et al*. (1986) reported that the change in the posture of the head may affect the size of the pharyngeal airway [34]. The change in the head posture was the product of muscular action trying to keep a patent airway especially the suprahyoid and infrahyoid muscles. Shelton & Bosma in 1962 showed that there was an increase in the airway space with the extension of the head. The same finding was found by Hellsing (1989) when lateral cephalometric radiographs were taken in both natural head position and with a twenty degrees extension [33]. The distance of the hyoid bone from the mandible was increased, the lower pharyngeal space was increased and a small increase occurred in the airway space between the dorsal surface of the tongue and the posterior pharyngeal wall. Another study by Muto., *et al.* (2002) showed that a change in head posture of l0 degrees was found to alter the anteroposterior pharyngeal airway by about 4 millimeters [35]. Stepovich (1965) stated that the position of the hyoid plane will change with the extension of the head and could reach the level of the third cervical vertebra [36].

Vertical skeletal pattern

Dunn., *et al*. (1973) reported that the bigonial width and gonial angle were inversely proportioned to the nasopharyngeal airway size, while the ramal height' antigonial notch height and mandibular body length were not related to the airway dimensions [37]. Roehm (1982) reported that the tongue volume was proportionately higher in open bite cases [38]. He found that the mandible rotates open and the tongue is postured forward in order to accommodate the tongue without impinging on the airway. Akcam., *et al*. (2002) found that in subjects with posteriorly rotated mandible the soft palate was greater in length and thickness than the normal [39]. The ratio between the soft palate length and the superior pharyngeal space was maintained generally to prevent speech disorders.

Joseph., *et al*. (1998) studied the vertical dimension and growth pattern by comparing normodivergent with hyperdivergent facial patterns [40]. They found that the hyperdivergent group had narrower anteroposterior pharyngeal dimension. This narrowing was particularly present at the level of the hard palate and at the level of the tip of the soft palate. De Freitas., *et al*. (2006) in similar study found that the subjects with Class I and Class II malocclusions and vertical growth patterns had significantly narrower upper pharyngeal airways compared to the normal growth patterns [41]. The tongue was more inferiorly and posteriorly positioned in the hyperdivergent Class I and Class II group. Gomez., *et al*. (2006) investigated the pre-adenoid space size and its relationship to the vertical facial type [42]. They reported that the pre-adenoid space was not significantly correlated with the maxillary/mandibular vertical relationships. Pae., *et al*. (2008) found that the brachycephalic subjects showed less change in the position of hyoid bone over time than both normal and dolichocephalic subjects [15]. They indicated that the upper airway in the brachycephalic subjects was less challenged by aging that required less compensatory changes. Wang T., *et al*. [48] using three dimentional study they found that Adult skeletal Class II subjects with vertical growth patterns have significantly narrower pharyngeal airways than those with normal or horizontal growth patterns, confirming an association between pharyngeal airway measurements and a vertical skeletal pattern.

Sagittal skeletal pattern

There were several studies that investigated the relationship between the skeletal patterns and the pharyngeal measurements. Mergen and Jacobs (1970) compared the nasopharynx size between normal and Class II malocclusion' they found that the depth of the nasopharyngeal airway was larger in subjects with normal occlusion while the convexity of the posterior wall of the nasopharynx was larger in Class II subjects [43]. They did not find significant associated between the size of the nasopharyngeal area and the anterior osseous facial convexity' Grauer., *et al*. (2009) compared the cone beam images of Classes I, II and III with normal, hypo and hyperdivergent patterns [18]. They did not find significant associated between the size of the nasopharyngeal area and the skeletal relationships' Ceylan and Oktay (1995) performed a study on the pharyngeal size in different skeletal patterns [44]. They observed that the measurements of the oropharynx area were inversely proportioned to the ANB angle, and was affected by the gender. Trenouth and Timms (1999) in their study found significant correlations between the airway dimension and the length of the mandible, the distance between third cervical vertebra-hyoid bone and the cranial base angle [45]. Abu Allhaija and Al-Khateeb (2005) studied the uvuloglosso- pharyngeal dimensions in different anteroposterior skeletal patterns [16]. They found that there were no significant differences in airway dimensions in the different three skeletal patterns. They found that there were significant weak correlation between the change in ANB angle and the position of the hyoid bone, and the width of the inferior pharyngeal space. Muto., *et al*. (2008) evaluated the pharyngeal airway space in three groups of females with mandibular retrognathia, prognathia, and normal subjects [35]. The pharyngeal airway was largest in the group with mandibular prognathism followed by the normal group and finally mandibular retrognathism group. Grauer., *et al*. (2009) applied the cone-beam computed tomography to study the three-dimensional configuration of the pharynx in different skeletal configurations [18]. They found significant differences in the inferior compartment of the airway between the different sagittal groups. No significant differences were found between the long, normal and short face-height groups. They found that the Class II subjects has smaller inferior pharyngeal airway, and were sloping forwards and narrower compared to Class III when viewed on sagittal and coronal cuts respectively. They mentioned in their study that there two important points to be considered in studying the pharyngeal airway. The first was considering the size of the face and the second was the patient's height and weight. This two could affect the airway dimensions.

Ricketts (1968) and Schulhof (1978) in their studied reported the presence of a relationship between the airway and the sagittal skeletal patterns [10,20]. On the other hand, de Freitas., *et al*. (2006) found in their study that the vertical growth pattern subjects had reduced upper pharyngeal airways [41]. The sagittal malocclusion type did not influence the upper or lower pharyngeal airway widths. Sosa., *et al*. (1982) showed that the nasopharyngeal characteristics did not have clear relationship in the subjects with Class I and Class II, Division I malocclusions [17]. Adamidis and Spyropoulos (1992) studied cephalometric radiographs of patients with Class III malocclusions [23]. They found that the patients with Class III malocclusions had more anterior position of the hyoid bone and a reverse inclination of its long axis to the mandibular plane and to the ramus. In the same study Adamidis and Spyropoulos (1992) found that girls had more "normal" position of the hyoid bone compared to boys [23]. They explained that for the girls because of their awareness of the presence of mandibular prognathism, they tend to posture the mandible and bring the incisors to edge-to-edge relationship to hide the prominent of the chin. Hakan., *et al*. in his study found that the oropharangeal airway volume differed signicantly especially between CIII Mandibular protrusion and CII madibular retrusion groups, with the former showing a larger volume. The only signicant difference for the NP volume was between CI and CII mandibular retrusion groups where a smaller volume for the CII mandibular retrusion group was observed [49].

Airway studies and CBCT

Evaluation of the upper airway has become an important diagnostic test in several subspecialties of dentistry (Tso, 2009), in part due to the controversial (Warren., *et al*. 1991) but potential impact of high resistance airways contributing towards an abnormal growth of the naso-maxillary complex, increasing the vertical facial dimension in young patients (Linder-Aronson, 1970) and the potential role of constricted airways in the pathophysiology of obstructive sleep apnea (OSA) (Haskell J., *et al*. 2009). Studies on the changes of upper airway dimensions have consisted of analyzing the post-treatment effects of RME with dental casts (Oliveira De Felippe., *et al*. 2008), human skull models (Gautam., *et al*. 2007) 2-dimensional cephalometric radiographs (Haas 1970), 3-dimensional imaging techniques including magnetic resonance images, CT, CBCT (Garrett 2007), acoustic rhinometry and computed rhinomanometry (Enoki., *et al*. 2009).

However, certain limitations exist in each of these studies. Acoustic rhinometry was found to lack accuracy when it comes to discerning expansion or constrictions less than 3 to 4mm (Djupesland., *et al*. 2001). Lateral and posteroanterior cephalometric radiographs have been traditionally used to compare the dimensional changes in the maxilla and the upper airway. However, the complexity of the 3D airway anatomy added to the superimposition of the bilateral structures, magnification differences and difficulties in landmark identification may well have overlooked important anatomical features relevant to the airway analysis, questioning the accuracy of 2-dimensional (2D) representations (Chung., et al. 2004). Major., *et al*. found that there was at best, a moderate correlation (r=0.68) between linear measurements of the upper airway in a 2D cephalometric film and the diagnosis of the upper airway blockage, suggesting that 2D cephalograms should be used only as a screening tool for airway obstruction [46]. The available 3D techniques including MRI and computed tomography may depict the true morphology of the airway; however, their use is limited by high radiation, high cost and restricted accessibility. Among all the existing 3D imaging techniques, CBCT has become an alternative technique to CT scanning for a comprehensive head and neck evaluation due to its significantly lower overall effective radiation dose and greater spatial resolution than medical CT, high contrast between the hard and soft tissues, lower cost and easier access and availability to dentists (Mah 2004, Ogawa 2007, Tso 2009). Despite the fact that with CBCT, it is not possible to discriminate between the various soft tissue structures, it is possible to determine the boundaries between soft tissues and air spaces making CBCT a potential diagnostic method to analyze airway dimensions (Lenza., *et al*. 2010).

Conclusion

With the above referred study the pharyngeal airway is sensitive to different anteroposterior. The Airway dimensions are subjected to change with retrognathic manbible and prognathic mandible comparing with normal mandible.

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Volume 3 Issue 5 May 2019