REVIEW ARTICLE

# The Origin of Pharyngeal Obstruction during Sleep

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***ABSTRACT:*** *This paper traces the development of the adult human pharynx through evolution, comparative anatomy, and development from infant to adult. Based on phylogeny and otogeny, an hypothesis for the occurrence of obstructive sleep apnea in the mature human is presented.*

**KEYWORDS:** obstructive sleep apnea, oropharynx, klinorynchy, evolution, pharynx

Obstructive sleep apnea (OSA) is characterized by repeated pharyngeal obstructions during sleep. The obstructions occur in the velopharyngeal, orophayngeal, and hypopharyngeal regions of the human pharynx. Man is the only animal to suffer from OSA although, arguably, the English bulldog also suffers from a form of sleep disordered breathing.*

What is it that is unique to the human pharynx that predisposes it to collapse during sleep? To answer this question one must investigate the evolution, comparative anatomy and development of the pharyngeal area.

Laitman[1] stated

> The acquisition and processing of oxygen and its byproducts is the primary mission of any air-breathing vertebrate. Chewing, walking, reproducing, thinking are all fine, but first one has to breathe. Anthropologists seem to forget this; evolution never does.

However, despite the importance of respiration to sustaining life, when one considers the muscles of the pharyngeal region in man, it becomes apparent that not one muscle has as its *primary* function dilation of the pharynx. The muscles commonly thought of as the pharyngeal dilator muscles are listed in Figure 2.

What could be the reason that a function so necessary to the life of man as breathing, while awake and asleep, does not have even one muscle dedicated to maintenance of patency of the upper airway? Could it be that pharyngeal dilation for respiration is not necessary in other mammals and was not necessary in the evolutionary development of man? To answer this question, one has to consider the function of the structures of the pharyngeal airway and compare the differences between other mammals and man.

Negus[2] performed postmortem dissections on many types of mammals and found that the epiglottis passes up behind the soft palate to guide the locking of the larynx directly into the nasopharynx. This provides a direct air channel from the external nares through the nasal cavities, nasopharynx, larynx, and trachea into the lungs. Food passes on either side of the interlocked larynx and nasopharynx into the esophagus without interfering with the patent airway. He concluded that the function of the epiglottis in mammals was to subserve the sense of smell by allowing the individual to breathe and eat at the same time. Further in all quadrupeds, such as the horse (Fig. 3), the tongue is located entirely within the oral cavity. (Even in the English bulldog the uvula and epiglottis are interlocked—see Fig. 1) Crelin[3] states that

> After an extensive survey of the literature and dissecting numerous specimens, a general pattern of vocal tract anatomy in the air-breathing vertebrates emerged. Except in the mature human, the tongue is located entirely within the oral cavity or mouth.

It would appear when analyzing air-breathing vertebrates other than the adult human, those with an interlocking epiglottis and uvula, with a straight airway and with a tongue totally housed within the oral cavity, muscles for pharyngeal dilation may be totally unnecessary

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*Hendricks et al[1] have stated that the English bulldog is "characterized by an abnormal upper airway anatomy, with enlargement of the soft palate and narrowing of the oropharynx." Despite the tendency for this breed to suffer sleep-disordered breathing and $O_2$ desaturation, the pharyngeal airway is unlike that of the adult human. It is, however, similar to the human infant and all nonbrachycephalic animals in that the tongue is contained totally within the oral cavity and, therefore, an oropharynx does not exist (Fig. 1). The development of an oropharynx, as shall be demonstrated in this article, is unique to the mature human. Because of this, the English bulldog cannot be considered an animal model of sleep-disordered breathing from which an exact correlation to adult human obstructive sleep apnea can be extrapolated. However, because of the anatomical similarities of the bulldog pharynx to the infant human, that is, the presence of an interlocking uvula and epiglottis, it is plausible that this animal might represent a model from which to study infantile obstructive sleep apnea and Sudden Infant Death Syndrome.

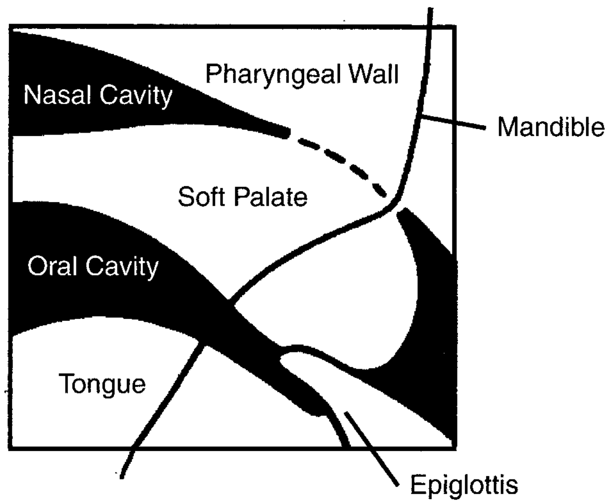


**FIG. 1.** The airway of the bulldog is extremely narrow in oral cavity and nearly obliterated in nasal cavity by the large soft palate. Furthermore, soft palate extends further caudally, overlapping epiglottis by almost 1 cm. After Hendricks et al. (4).

to maintain patency of the airway. In these animals, the oropharynx does not exist.

One other factor plays a crucial role in the development of obstructive sleep apnea in the human. The anatomy of the human newborn and very young infants (Fig. 4) closely approximates the anatomy of the upper respiratory tract of primates in particular and mammals in general.[5] The close approximation and locking of the uvula and epiglottis allows for the simultaneous suckling of milk and breathing. At an early stage in the ontogenetic development of the human (approximately 18 months), the laryngeal complex migrates from its original subcranial position to lie opposite the fifth cervical vertebra. However, the epiglottis does not undergo any significant morphological change as a result of the relocation of the larynx. This leads to the fact that while in all other animals and the postpartum human infant the epiglottis interdigitates with the soft palate, in the developing human it is increasingly unable to do so. As the interdigitation of these structures effectively resulted in discrete pathways for respiration and deglutition, the development of specific musculature to maintain patency of the pharynx was unnecessary. In the mature human, however, the anterior wall of the respiratory tube is breached throughout the extended length of the newly developed oropharynx. The development of this wide, soft-walled oropharyngeal structure has some advantages in that it provides a resonating chamber in which format frequencies (at the basis of human speech) can be generated,[6] but also provides the opportunity for sleep-induced collapse.

The adult human pharynx differs substantially from the human infant and other air-breathing mammals. As an individual evolutionarily assumes an erect posture, changes occur in the relationship between the position of the foramen magnum at the base of the skull and the spinal column as well as between the braincase (neurocranium) and the facial skeleton (splanchnocranium). The human facial skeleton lies below the frontal region of the braincase rather than in front of it, as in most quadrupedal animals. The facial migration that results in this positioning of the splanchnocranium, known as klinorynchy, constricts the available subcranial space to the extent that a change in pharyngeal and laryngeal morphology is necessitated.[6] The process of klinorynchy can be summarized in Figure 5.

Crelin[7] writes that

> In the present day apes, I found that the tongue occupies the entire oral cavity with the jaws closed, and its length is directly related to the length of the oral cavity. Thus, the

| MUSCLE | ACTION |
|---|---|
| Digastricus | Elevates hyoid; depresses mandible |
| Genioglossus | Protrudes tongue (inf. fibers); depresses tongue (mid. fibers) |
| Geniohyoid | Elevates hyoid; depresses mandible |
| Levator Veli Palatini | Elevates Soft Palate |
| Musculus uvulae | Shortens the uvula |
| Palatoglossus | Elevates and retracts the tongue |
| Palatopharyngeus | Elevates larynx |
| Salpingopharyngeus | Elevates larynx |
| Styloglossus | Retracts and elevates tongue |
| Stylohyoid | Elevates and retracts hyoid |
| Stylopharyngeus | Elevates larynx |
| Tensor veli palatini | Opens auditory tube; tenses soft palate |

**FIG. 2.** The actions of the pharyngeal dilator muscles.

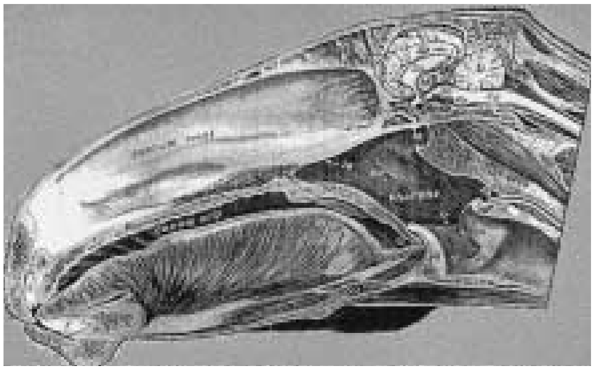

**FIG. 3.** Sagittal view of horse pharynx. During quiet respiration, the soft palate of the horse is in snug contact with the epiglottis because the larynx is locked into the nasopharynx. Air passes through the external nares, through the nasal cavities, through the larynx into the trachea. Simultaneously, liquid can be swallowed from the oral cavity, on either side of the larynx into the pharynx and esophagus. The tongue is located entirely within the oral cavity and is not situated in the pharynx.[3] (Reprinted from Getty (8), with the permission of W.B. Saunders.)

length of the adult tongue is shortest in the gibbon, longer in the chimpanzee, even longer in the orangutan and longest in the gorilla. The length of the oral cavity becomes smaller as one passes from an australopithecine the size of Mrs. Ples *to Homo erectus* to early and recent *Home sapiens.* But, because the posterior part of the tongue descended into the neck as the oral cavity became shorter, the tongue maintained its original length. (Fig. 6)

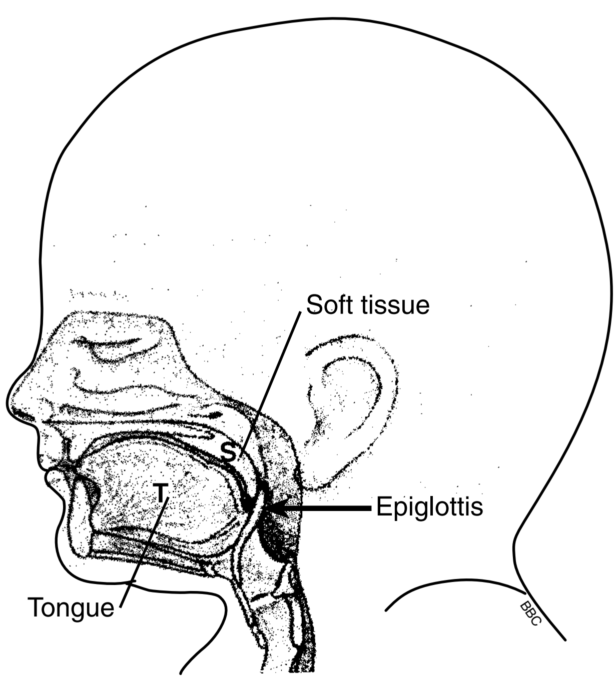


**FIG. 4.** Sagittal section of head of newborn full-term infant. The epiglottis is in direct contact with the soft palate (S) because the larynx is locked into the nasopharynx. In the newborn human infant the tongue is located entirely within the nasal cavity.[3] (Reprinted with the permission of Dr. Edmund Crelin.[9])

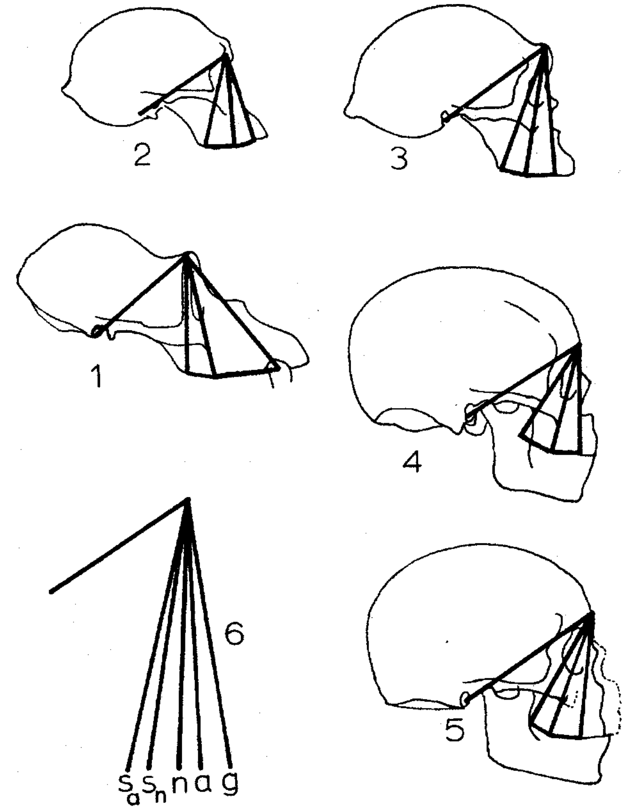


**FIG. 5.** Interpretations of the facial frameworks of a hominoid and a number of hominid species. A line drawn from the external auditory meatus to the apex of the supraorbital torus indicates how the facial framework is progressively "tucked" beneath the cranium in this series of animals. This kind of craniofacial flexion is described as "klinorynchy." **1,** Gorilla gorilla, a hominoid. The skull is markedly prognathous. **2,** Australopithecus africanus (Mrs. Ples', either ancestral to, or very close to the ancestry of, modern man. **3,** Homo sapiens neandertalensis (a primitive variety of man). **4,** Homo sapiens sapiens (modern man) **5,** Homo sapiens sapiens, an individual with extreme craniofacial flexion who represents phenotypic expression of an extreme variation in a parameter undergoing a phylogenetic change. **6,** The progressive development of craniofacial flexion in the above speciaes is demonstrated by the angle between the line joining the external auditory meatus and the supraorbital torus and the facial skeleton strut passing through the postorbital bar. **g,** Gorilla (67 degrees); **a,** Australopithecus (60 degrees); **n,** Homo sapiens neandertalensis (55 degrees) **Sn,** Homo sapiens sapiens (normal) (49 degrees); **Sa,** Homo sapiens sapiens (abnormal) (44 degrees). None of the values given are meant to be definitive; they are only indicative of the trend described.[9]

To accommodate to the smaller subcranial space, the tongue folds into the pharynx forming the anterior wall of the pharynx (Fig. 7). With the descent of the larynx and the development of a soft-walled oropharynx that supports speech, certain disadvantageous morphological characteristics also develop. The anatomical formation requires the pharynx to perform three distinct roles requiring totally different muscular activities: respiration, deglutition, and phonation. For deglutition, the

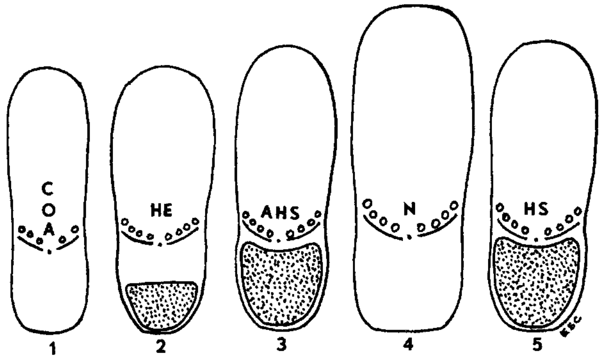


**FIG. 6.** "An illustration depicting the relative sizes and shapes of the adult homonid tongue during evolution. Each tongue is shown to be completely flat. The stippled areas represent the vertical part of the tongue when it forms the anterior wall of the oropharynx. The circles are the vallate papillae located along the junction of the anterior two thirds and the posterior one third of the tongue. The tongue labelled C, O, and A represents one from an adult male chimpanzee, an adult orangutan, or a man-ape australopithecine homonid, such as Mrs. Ples. The tongue labelled HE represents one of a *Homo erectus* homonid such as Peking woman. The tongue labelled AHS represents one of an archaic *Homo sapiens* homonid such as Steinheim woman. The tongue labelled N represents one of a classic Neanderthal homonid such as La Chapelle-aux-Saints. The tongue labelled HS represents one of a present-day *Homo sapiens* male. (Reprinted with the permission of Dr. Edmund Crelin.[3])

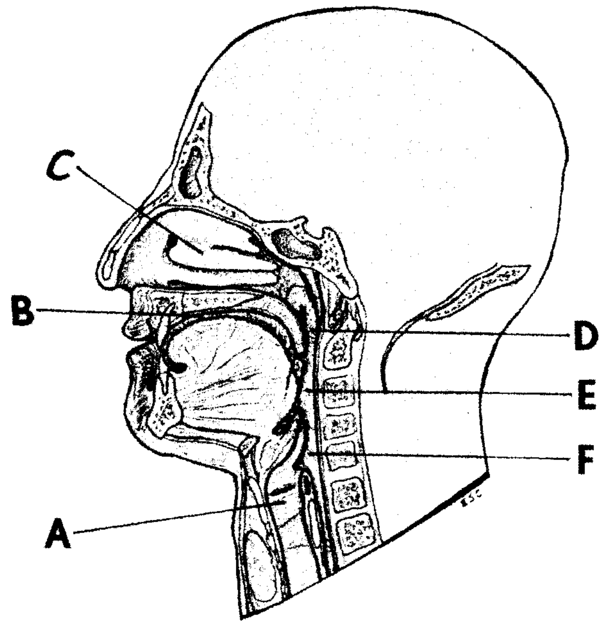


**FIG. 7.** Sagittal section of human adult pharynx. A: larynx, B: oral cavity, C: nasal cavity, D: nasopharynx (velopharynx), E: oropharynx, F: laryngopharynx (hypopharynx). The oropharynx extends from the tip of the uvula to the tip of the epiglottis. The oropharynx is unique to modern man. (Reprinted with the permission of Dr. Edmund Crelin.[3])

pharynx assumes the role of a flexible tube whose muscles, namely the pharyngeal constrictors, force food from the oral cavity into the esophagus. For phonation, the mature human pharynx is a muscular tube that can change in length and shape to alter the sounds passing through it. Once again, specific muscles alter the shape of the pharynx and larynx to perform this function. Finally, the pharynx must remain as a rigid tube to allow air passage without collapse during sleep. No muscle or group of muscles assumes this function as a primary role leaving the pharynx subject to collapse and obstruction during certain conditions of respiration. This allows for an occasional misdirected bolus of food to occlude the airway and for the pharyngeal airway to collapse under specific conditions of respiration.

In the presence of a patent nasal airway, using an evolutionary model to consider function of the soft palate and uvula, one could postulate that the soft palate and uvula, in the adult, continue to attempt to direct airflow toward the stable, nonflexible posterior pharyngeal wall. This mimics the airflow pattern achieved in situations where the uvula and epiglottis are interlocked. If this is true, then laser-assisted uvuloplasty (LAUP) and uvulopalatapharygoplasty (UPPP) may be detrimental to the patient's total recovery from OSA by removing the tissues that could potentially be utilized to direct airflow to the noncollapsible portion of the airway.

Because the oropharynx is unique to modern man and because modern man is the only mammal (with the possible exception of the brachycephalic English bulldog, an achondroplastic dwarf) to suffer from obstructive sleep apnea, it would seem reasonable to assume that the key to understanding the physiology and pathogenesis of obstructive sleep apnea may lie in the space between the uvula and epiglottis known as the oropharynx. This naturally assumes that all other factors (that is a normal size soft palate without excessive secondary folds, a normal size uvula, a patent nasal passageway, an oropharynx devoid of excessive tonsillar tissue or redundant tissue on the posterior pharyngeal wall) are equal.

Enlow and Hans[10] state

> The facial and pharyngeal airway is a space determined by the multitude of separate parts comprising its enclosing walls. The configuration and dimensions of the airway are thus a product of the composite growth and development of the many hard and soft tissues along its pathway from nares to glottis. Although determined by surrounding parts, those parts in turn are dependent upon the airway for maintenance of their own functional and anatomic positions. If there develops any regional childhood variations along the course of the airway that significantly alters its configuration or size, growth then proceeds along a different course, leading to a variation in overall facial assembly that may exceed the bounds of normal pattern. The airway functions, in a real sense, as a keystone for the face.

Attempts are being made to formulate a morphometric model[11] that uses intraoral measurements of the oral cavity in conjunction with body mass index (BMI) and neck circumference. Morphometric measurements of existing anatomical landmarks measure one or both of two growth and development possibilities. Morphometric measurements measure the end result or outcome of growth and development either (1) by the way the skeleton influences the developing soft tissues or (2) by the way the developing airway determines the growth of the skeleton or by a combination of both.

Regardless of which element of the facial growths controls and determines the growth of the other, one comes to the conclusion that all anatomical measurements, whether they be morphometric, cephalometric or with CT or MRI, are actually measuring similarity or dissimilarity to animal, prehistoric man, and human infant. The data realized from these measurements could be interpreted as showing that the closer we are to a Neanderthal or animal-like structure, the less likely we are to have apnea.

The anterior pharyngeal wall, which is made up of the posterior border of the tongue, is paramount to the formation of OSA. The next logical assumption has to be that the primary pathogenic anatomical cause of OSA is the posterior border of the tongue. Roberts[6] states that as the mandible is moved forward, the soft palate and uvula follow. Therefore, removal of the uvula and soft palate would seem to be unnecessary for the resolution of OSA, once again granting that the neither the nasal passages nor velopharynx or oropharynx is obstructed with redundant tissue. In fact, excision of the uvula and soft palate may actually increase the likelihood of OSA if the soft palate's function is to direct airflow toward the posterior wall of the pharynx. It would be logical to assume that if the tongue could be moved out of the oropharynx immediately prior to the apneic incident, then the obstructive incident would not occur (once again granting that neither the nasal passages nor velopharynx or oropharynx is obstructed with redundant tissue). Indeed research shows a high degree of treating OSA with a tongue-retaining device.[12,13]

## CONCLUSION

This paper traces the development of the adult human pharynx from air-breathing vertebrates other than man, through the evolutionary development of modern man and through maturation from infancy to adulthood. It presents the hypothesis that because the adult human pharynx developed an oropharynx, not present in other air-breathing vertebrates, as a result of the evolvement of upright posture and speech; the adult human did not ontogenetically develop specific musculature to dilate and maintain dilation of the pharynx. A corollary to this hypothesis might state that if an interlocking soft palate and epiglottis were evolutionarily responsible for maintaining a patent airway in obligate nose-breathing mammals, these organs might still be responsible, in the mature human, for the direction of laminar airflow. It would, therefore, stand to reason that surgical excision of the uvula and soft palate might eventually lead to a more critical problem in the patient's long-term follow-up. It would also be reasonable to assume that treatment of OSA should be centered upon maintaining patency in the oropharyngeal region of the pharynx, with particular attention paid to the anterior wall of the oropharynx, that is, the posterior border of the tongue.

If the development of the airway is indeed crucial to the development of the facial structure and if development of skeletal structure is a critical factor in the occurrence of OSA as a child ages, it is essential to be able to forecast which children will develop OSA. Interceptive treatment could then be instituted in one of two ways:

(a) Continuous positive air pressure (CPAP) applied early in the development of the adult pharynx to controls size of the upper airway and thus guide development of the skeletal structure, or
(b) Early orthodontic interception to guide development of the skeletal structures.

Phylogeny and otogeny should be considered when developing treatment modalities for OSA.

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