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A Review of Upper Airway Anatomy and Physiology of the Horse

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Take Home Message

Respiratory dysfunction is second only to musculoskeletal injuries as a cause of poor performance in athletic horses. Some knowledge of the anatomy of the horse's upper airway is essential to accurate diagnosis and treatment of these diseases.

Introduction

The physiologically distinct functions of breathing, deglutition and vocalization in the horse rely on the carefully orchestrated action and anatomic arrangement of the nasopharynx, the common conduit through which both air and ingesta pass. Simply conceived, it is a muscular tube suspended rostrally from the pterygoid and palatine bones, and anchored caudally on portions of the hyoid apparatus and the laryngeal cartilages. During strenuous exercise, airflow velocities and airway pressures fluctuate tremendously, and appropriate sensory and motor activity must occur to maintain airway patency. Failure of these anatomic structures or neuromuscular activities results in a constellation of clinical disorders, ranging from exercise intolerance to dysphagia.

Anatomy of the Nasopharynx

While the nasopharynx may be simply conceptualized as a muscular tube, it is an anatomically and functionally complicated structure composed of multiple muscle groups including the dorsal pharyngeal constrictors and dilators, the hyoid muscles, soft palate muscles and muscle of the tongue, and innervated by several cranial nerves, including branches of C.N. V, IX, X, and XII. At the microscopic level, the nasopharyngeal mucosa is comprised of a pseudostratified columnar epithelium studded with goblet cells, lymphoid follicles and sensory receptors of the glossopharyngeal (CN IX) and trigeminal (CN V) nerves. These are principally tactile receptors important for airway protection, stimulating the gag reflex, and for airflow detection, stimulating airway dilation during inhalation. Numerous mucosal pressure receptors blanket the laryngeal mucosa and these mechanoreceptors sense subatmospheric pressures within the airway. Increased activity of these receptors reflexively enhances tone of upper airway dilating and stabilizing muscles thus preventing dynamic collapse of the airway. Following topical anesthesia of the laryngeal mucosa, horses exhibited circumferential collapse of the nasopharynx both during treadmill exercise and at rest while the nares were occluded, suggesting that the activity of the pressure-sensing receptors is required for optimal dilation and stability of the nasopharynx (Figs. 1a & 1b).

Figure 1a. Image is an endoscopic image of a normal nasopharynx.

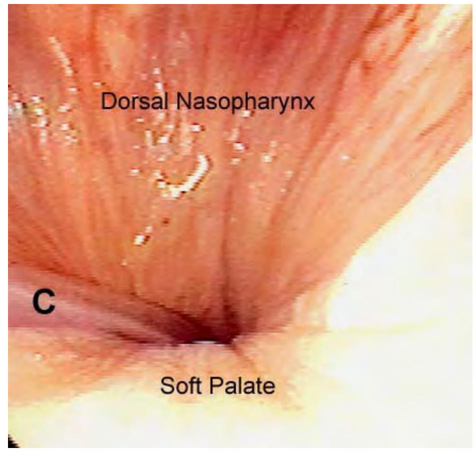
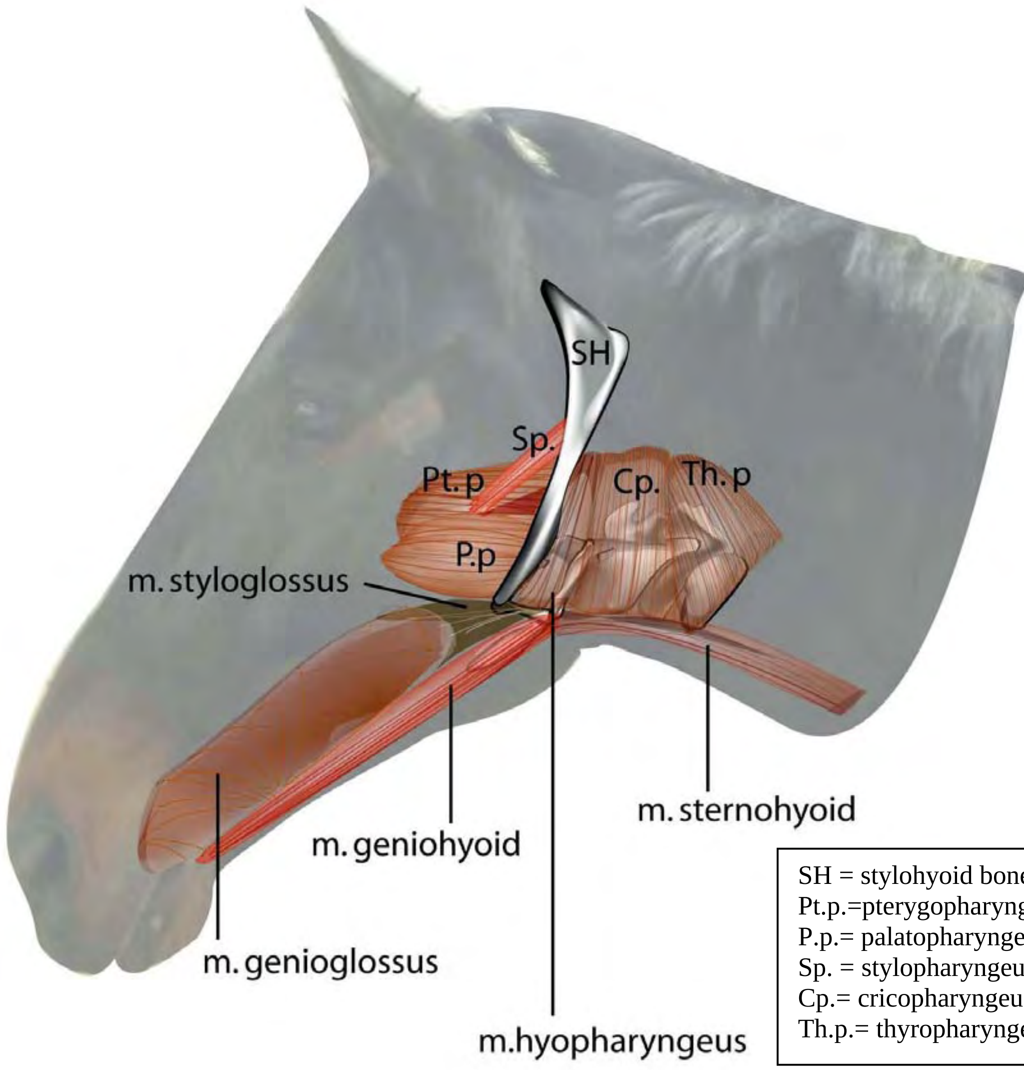


Figure 1b. Above, endoscopic image of the nasopharynx following topical anesthesia of the laryngeal mucosa.

Dorsal pharyngeal muscles: The action of the dorsal pharyngeal constricting muscles and the stylopharyngeus muscle is responsible for stiffening and dilating the nasopharynx. The middle pharyngeal constrictor (hyopharyngeus muscle) and superior pharyngeal constrictor (palatopharyngeus and pterygopharyngeus muscles) form the dorsal and caudolateral pharyngeal walls contraction and shortening of these muscles form a sphincter, moving the food bolus caudally into the esophagus during swallowing (Fig. 2). During breathing, these muscles have tonic and phasic expiratory activities that help to support the nasopharynx. The major dilating muscle of the dorsal nasopharynx is the stylopharyngeus muscle. This muscle originates on the axial aspect of the distal portion of the stylohyoid bone and courses rostroventrally to ramify in the wall of the dorsal nasopharynx, by passing between the pterygopharyngeus and palatopharyngeus muscles (Fig. 3a). Contraction of the stylopharyngeus muscles pulls the pharyngeal wall dorsally, to receive a food bolus during swallowing. In a similar manner, during breathing, contraction of the stylopharyngeus muscle pulls the nasopharyngeal wall dorsally thereby supporting the dorsal wall of the nasopharynx and preventing dynamic collapse of this area during inspiration. Evidence of contraction of the stylopharyngeus muscle can be seen as "dimpling (arrows)" of the dorsopharyngeal wall, especially after swallowing (Fig. 3b). Experimentally creating stylopharyngeus muscle dysfunction by anesthetizing the glossopharyngeal nerves caused collapse of the dorsal nasopharynx and inspiratoryobstruction in exercising horses. However, glossopharyngeal anesthesia did not result in dysphagia or any quantifiable swallowing dysfunction in horses.

Soft Palate**:** The nasopharynx is demarcated by the soft palate, which completely divides the pharynx into nasal and oral compartments in the horse. Because the horse is an obligate nasal breather, it is critically important that the soft palate remains ventral to the epiglottis, except during swallowing, to allow unimpeded nasal breathing. The soft

Figure 2



SH = stylohyoid bone,
Pt.p.=pterygopharyngeus;
P.p.= palatopharyngeus;
Sp. = stylopharyngeus;
Cp.= cricopharyngeus;
Th.p.= thyropharyngeus.

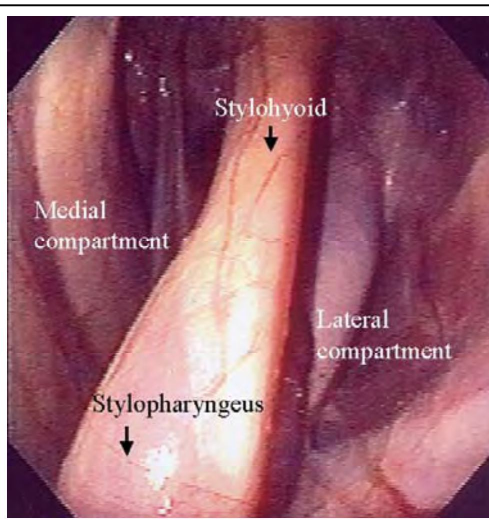


Figure 3a

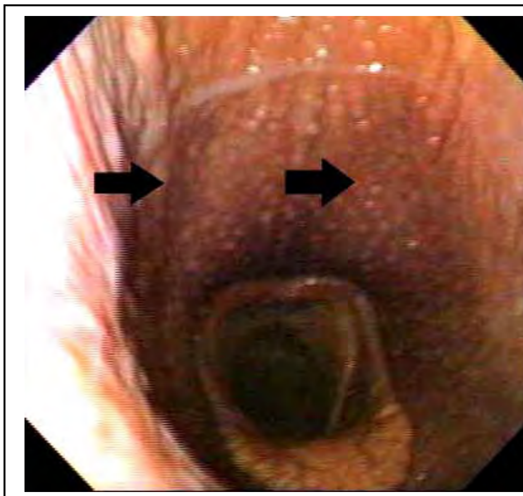


Figure 3b

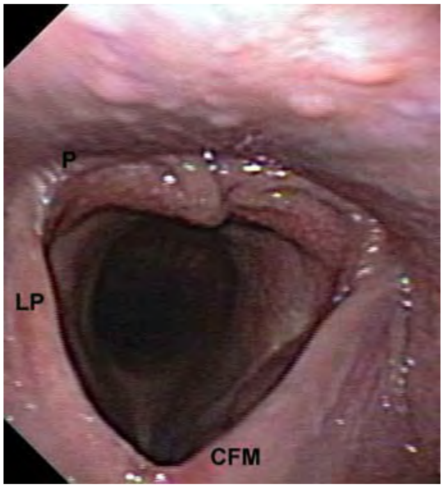


Figure 3c. Margins of the soft palate.

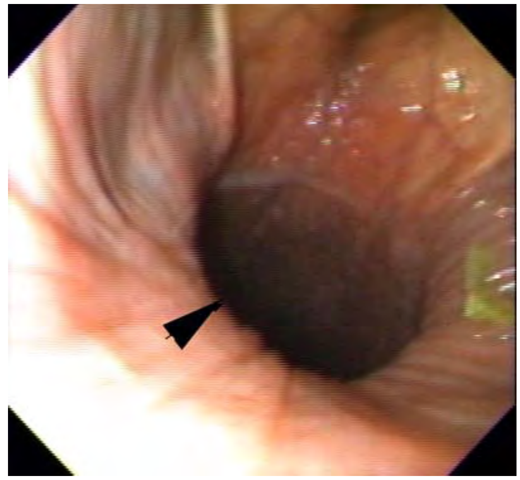


Figure 4

palate extends caudally from the hard palate to the base of the larynx and consists of the oral mucous membrane, which contains ductile openings of the palatine glands, the palatine glands, the palatine aponeurosis, palatinus and palatopharyngeus muscles, and the nasopharyngeal mucous membrane. The caudal free margin (CFM) of the soft palate continues dorsally, on either side of the larynx, forming the lateral pillars (LP) of the soft palate. These pillars unite dorsally, forming the posterior pillar of the soft palate or the palatopharyngeal arch (P) (Fig. 3c). The position of the soft palate is determined by the coordinated activity of groups of antagonistic muscles, which include the levator veli palatini, tensor veli palatini, palatinus, and palatopharyngeus muscles. The levator veli palatine muscle, innervated by the pharyngeal branch of the vagus nerve, acts to elevate the soft palate during swallowing and vocalization. The action of the levator veli palatini muscle can be seen during endoscopic examination of the upper airway when the gag reflex is stimulated. A “sling (arrow)” forms within the nasopharynx as the nasopharynx contracts into a sphincter (Fig. 4). The tensor veli palatini is a flat, fusiform muscle innervated by the mandibular branch of the trigeminal nerve that travels with the levator veli palatine muscle along the lateral walls of the nasopharynx and the lateral lamina of the guttural pouch. Its tendon is reflected around the hamulus of the pterygoid bone, where it is lubricated by a bursa. The tendon then ramifies in the palatine aponeurosis. Contraction of this muscle tenses the palatine aponeurosis and, therefore, the rostral portion of the soft palate, and depresses this portion of the soft palate toward the tongue. Contraction of the tensor veli palatini muscle also aides in opening the pharyngeal opening of the guttural pouch. Dysfunction of the tensor veli palatine muscles results in collapse of the rostral aspect of the soft palate. This portion of the soft palate billows dorsally into the airway during inhalation and obstructs airflow. These horses make a respiratory noise during exercise and have some degree of exercise intolerance. Rostral soft palate collapse has occasionally been described as a prelude to DDSP. However, in experimental horses and clinical cases, dysfunction of the rostral soft palate can occur without DDSP as a sequela. The *palatinus* muscle (uvula retractor muscle) consists of two fusiform muscles that lie on either side of midline of the soft palate, beneath the nasopharyngeal mucosa, extending caudally from the hard palate. These muscles attach to the caudal aspect of the palatine aponeurosis and terminate near the caudal free margin of the soft palate. A small muscle bundle arising from the lateral aspect of each muscle continues a short distance caudodorsally into the palatopharyngeal arch. Contraction of the palatinus muscle shortens the soft palate. The *palatopharyngeus* muscle originates from the palatine aponeurosis and the lateral border of the palatinus muscle. It travels caudally along the lateral wall of the nasopharynx to the pharyngeal raphe, forming part of the superior constrictor muscle group. Branches of the pharyngeal branch of the vagus nerve innervate Palatinus, palatopharyngeus, and members of the dorsal pharyngeal constrictor group. Contraction of this muscle shortens the soft palate and draws the larynx and esophagus toward the root of the tongue. Dysfunction of the palatinus and palatopharyngeus muscles has been implicated in intermittent dorsal displacement of the soft palate and dysphasia in horses.

Tongue: The tongue is integral to positioning the hyoid apparatus, one of the key support structures of the nasopharynx. There are three intrinsic tongue muscles the genioglossus, hyoglossus, and styloglossus. The genioglossus is the largest intrinsic tongue muscle and originates from the medial surface of the mandible, just caudal to the symphysis (Fig. 4). Styloglossus contraction retracts the tongue. Contraction of the genioglossus muscle protracts the tongue and pulls the basihyoid bone rostrally. Genioglossus also acts with the hyoglossus muscle to depress and retract the tongue. Hyoglossus and genioglossus activity are synchronous with respiration and activity of these muscles correlates well with increases in pharyngeal airway size during breathing. Indeed, retraction and depression of the tongue improved airflow, function and enhanced pharyngeal stability in several species. Therefore, it seems that tongue depression may be the critical force needed to dilate and stabilize the nasopharynx in horses. This is perhaps why the tongue-tie has been shown to be ineffective in expanding the dimensions of the nasopharynx or preventing dorsal displacement of the soft palate in affected horses.

Hyoid muscles: Other muscles that attach to the hyoid apparatus and critically affect the nasopharyngeal architecture include the geniohyoideus, sternohyoideus and sternothyroideus, omohyoideus, and thyrohyoideus. The geniohyoideus muscle is a fusiform, paired muscle that lies on the ventral surface of the tongue. The geniohyoideus originates from the medial surface of the mandible (near the genioglossus' origin) caudal to the symphysis and inserts on the basihyoid bone. The omohyoideus, sternohyoideus and sternothyroideus muscles are accessory respiratory muscles that insert on the manubrium and extend cranially. These muscles are called accessory muscles because their respiratory activity is somewhat silent during resting breathing but increases with exertion and exercise. The sternothyroideus inserts on the caudal abaxial aspect of the thyroid cartilage, and the sternohyoideus inserts on the basihyoid bone and the lingual process of the hyoid apparatus. Contraction of these muscles results in caudal traction of the hyoid apparatus and larynx, dilating the pharyngeal region. In summary, the hyoid moves rostrally when the geniohyoid and genioglossus muscles contract and in the opposite direction when the sternohyoid and sternothyroid muscles contract. The complex results of these muscles yield a more cranioventral position of the basihyoid bone, and an increase in the diameter and stability of the nasopharynx in exercising horses.

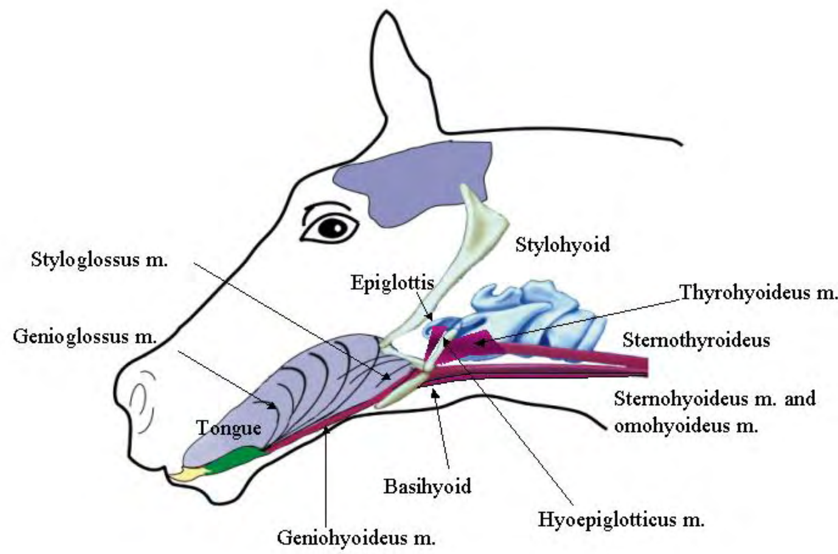


Figure 5

The *thyrohyoideus* is a flat rectangular muscle attached to the lateral surface of the thyroid cartilage lamina that inserts on the caudal part of the thyrohyoid bone (Fig. 5). It moves the hyoid bone caudally or the larynx rostrally and dorsally. In studies evaluating the electromyographic activity of some "extrinsic" nasopharyngeal muscles during exercise, Ducharme et al., observed decreased thyrohyoideus muscle activity prior to soft palate displacement in one horse. Investigations by Tsukroff et al. reveal that transection of a combination of the following muscles results in dorsal displacement of the soft palate in horses: thyrohyoideus, omohyoideus, sternohyoideus and hyoepiglotticus muscles. The displacement observed was associated with a more caudal positioning of the basihyoid bone. In subsequent studies thyrohyoideus muscle resection caused intermittent dorsal displacement of the soft palate in exercising horses. As well, thyrohyoideus muscle prosthesis created by placing a suture through the basihyoid bone and the thyroid cartilage returned airway function to normal such that dorsal displacement of the soft palate no longer occurred in any of these horses. These data clearly suggests that more cranial positioning of the larynx relative to the hyoid bone improves soft palate stability and that thyrohyoideus muscle dysfunction may be the likely etiology of intermittent dorsal displacement of the soft palate in horses.

Larynx

The larynx forms the communicating channel between the pharynx and the trachea and functions during breathing, vocalization, and deglutition. The larynx is composed of cartilage and muscle and is covered with a mucous membrane. The laryngeal cartilages include the cricoid, thyroid, and epiglottic cartilages, which are unpaired, and the

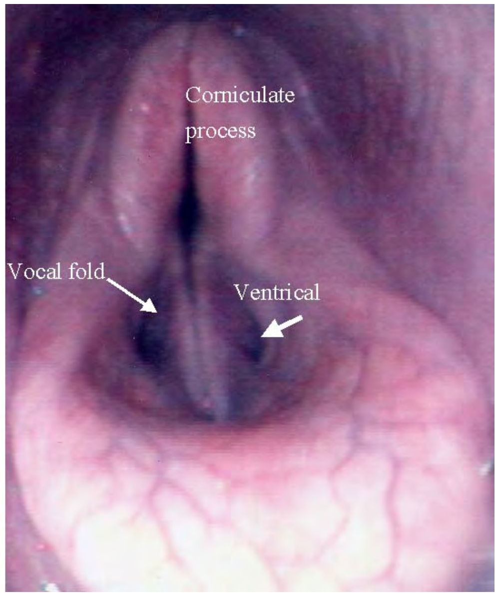


Figure 6

arytenoid cartilages, which are paired. The arytenoids cartilages form the dorsal border of the rima glottides. They are trianglular in shape with a dorsal muscular process, which serves as the origin for the cricoarytenoideus dorsalis muscle, a ventral vocal process serving as the attachment of the vocal ligament, and the rostral apex which forms the corniculate process. The arytenoid cartilages are positioned on either side of the cricoid cartilage and are connected to it by the cricoarytenoid articulations. The articulation is a diarthrodial joint that allows the arytenoid cartilage to rotate dorso-laterally during abduction and axially during adduction. The mucous membrane covering the epiglottic cartilage reflects off the lateral border of the epiglottis and blends with the mucous membrane covering the corniculate processes of the arytenoid cartilages, forming the aryepiglottic folds. The mucous membrane covers the vocal ligament, forms the vocal folds, and lines the lateral ventricles, forming the laryngeal saccules (Fig. 6). These saccules are 2.5 cm deep with a capacity of 5 to 6 ml. They extend between the medial surface of the thyroid cartilage and the ventricularis and vocalis muscles.

The intrinsic laryngeal muscles produce changes in caliber of the rima glottidis by abducting and adducting the corniculate processes of the arytenoid cartilages and the vocal folds and hence, altering airway resistance. These actions are accomplished by the contractions of the intrinsic laryngeal muscles. The cricoarytenoideus dorsalis is the principal abductor muscle that widens the laryngeal aperture by abducting the corniculate process of the arytenoid cartilage and tensing the vocal folds. The thyroarytenoideus, arytenoideus transversus, and the cricoarytenoideus lateralis muscles adduct the corniculate processes of the arytenoid cartilages, narrowing the rima glottidis and protecting the lower airway during swallowing. The cricothyroideus muscle, another vocal fold tensing muscle, receives efferent motor innervation from the external branch of the superior laryngeal nerve, a branch of the vagus nerve, while all other intrinsic

Figure 7

Figure 8

laryngeal muscles receive motor innervation from the recurrent laryngeal nerve, which is also a branch of the vagus nerve.

The epiglottis is principally composed of elastic cartilage and rests on the dorsal surface of the body of the thyroid cartilage and is held there by the thyroepiglottic ligaments. The position of the epiglottis is controlled by the position of the larynx, and hyoid apparatus, and by contraction of the hyoepiglotticus muscle, which is the only muscle that attaches to the epiglottis. The hyoepiglotticus is a bilobed extrinsic laryngeal muscle that originates on the basihyoid bone in horses, and inserts on the ventral body of the epiglottis. In horses, contraction of the hyoepiglotticus muscle pulls the epiglottis toward the basihyoid bone, depressing it against the soft palate, enlarging the airway. The hyoepiglotticus muscle has respiratory-related electromyographic activity in horses that increases with exercise intensity and breathing effort. Furthermore, electrical stimulation of the hyoepiglotticus muscle depresses the epiglottis ventrally against the soft palate, changing the conformation of the epiglottis in some horses (Fig. 7). The hyoepiglotticus muscle is likely an upper airway dilating muscle, which functions to enlarge the airway, thereby decreasing airway resistance in exercising horses. In addition to dilating the aditus laryngis, contraction of the hyoepiglotticus muscle stabilizes the epiglottis during inspiration, preventing its prolapse through the rima glottides (Fig. 8). Retroversion of the epiglottis is described clinically in exercising horses and can be created experimentally by anesthesia of the hypoglossal nerves. Blockade of these nerves creates hyoepiglotticus dysfunction, and dysfunction of other hyoid muscles including geniohyoideus and genioglossus, and suggests that the clinical problem may be due to paresis of the hyoepiglotticus muscle or other muscles involved in controlling the position of the basihyoid. Active control of epiglottis position by the hyoepiglotticus muscle apparently stabilizes the epiglottis and vigorous recruitment of the muscle activity during inhalation dilates the airway and maintains the nasal breathing route in horses during intense exercise. Conformational changes in the epiglottis that occur during exercise, respiratory stimulation, sedation, or nasal occlusion may not be abnormal, but may be the result of normal activity of the hyoepiglotticus muscle.

Though we have much to learn, it is becoming clearer how deficits of individual muscle groups result in diminished airway patency. Diseases such as dorsal displacement of the soft palate, epiglottic retroversion, various forms of nasopharyngeal collapse and laryngeal hemiplegia have been created experimentally by anesthetizing specific cranial nerves or transecting specific muscles in horses.

References

1. Feroah TR, Forster HV, Pan LG, et al. Reciprocal activation of hypopharyngeal muscles and their effect on upper airway area. J Appl Physiol 2000;88(2):611-626.
2. Tessier C, Holcombe SJ, Derksen FJ, et al. Effects of stylopharyngeus muscle dysfunction on the nasopharynx in exercising horses. Equine Vet J. 2004 May;36(4):318-23.
3. Fuller DD, Williams JS, Janssen PL, et al. Effect of coactivation of tongue protrudor and retractor muscles on tongue movements and pharyngeal airflow mechanics in the rat. J Physiol 1999;519(2):601-613.
4. Sisson S. Equine Digestive System. In: Getty R, ed. Sisson and Grossman's the anatomy of domestic animals. 5th ed. WB Saunders, Philadelphia 1975.