Activity of selected rostral and caudal hyoid muscles in clinically normal horses during strenuous exercise

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Objective—To determine the phase and quantitate the electromyographic (EMG) activity of the genioglossus, geniohyoideus, hyoepiglotticus, omohyoideus, sternohyoideus, sternothyroideus, and thyrohyoideus muscles of clinically normal horses during strenuous exercise.

Animals—7 clinically normal adult horses (2 Thoroughbreds and 5 Standardbreds).

Procedures—Bipolar electrodes were surgically implanted in the aforementioned muscles, and horses were subjected to an incremental exercise test on a high-speed treadmill. The EMG, heart rate, respiratory rate, and static pharyngeal airway pressures were measured during exercise. The EMG was measured as mean electrical activity (MEA). The MEA values for maximal exercise intensity (13 or 14 m/s) were expressed as a percentage of the MEA measured at an exercise intensity of 6 m/s.

Results—MEA was detected during expiration in the genioglossus, geniohyoideus, sternohyoideus, and thyrohyoideus muscles and during inspiration in the hyoepiglotticus and sternothyroideus muscles. Intensity of the MEA increased significantly with exercise intensity in the genioglossus, geniohyoideus, and hyoepiglotticus muscles. Intensity of the MEA increased significantly in relation to expiratory pharyngeal pressure in the geniohyoideus and hyoepiglotticus muscles.

Conclusions and Clinical Relevance—Once exercise intensity reached 6 m/s, no quantifiable additional increase in muscular activity was detected in the omohyoideus, sternothyroideus, and thyrohyoideus muscles. However, muscles that may affect the diameter of the oropharynx (genioglossus and geniohyoideus muscles) or rima glottis (hyoepiglotticus muscle) had activity correlated with the intensity of exercise or expiratory pharyngeal pressures. Activity of the muscles affecting the geometry of the oropharynx may be important in the pathophysiologic processes associated with nasopharyngeal patency. (Am J Vet Res 2008;69:682–689)

Stability of the nasopharynx in horses reportedly is influenced by intrinsic and extrinsic factors. Most of the information about stability of the nasopharynx has been obtained through studies in which investigators evaluated the effect of a specific dysfunction through denervation or muscle resection-transection. Currently, knowledge is more advanced about intrinsic factors than extrinsic factors. The tensor veli palatini confers stability to the rostral aspect of the soft palate to stabilize the rostral and ventral aspects of the nasopharynx. The palatinius and palatopharyngeus muscles stabilize the caudal aspect of the nasopharynx, specifically the caudal half of the soft palate, and dysfunction of these muscles is associated with DDSP. The caudal stylopharyngeus muscles stabilize the roof of the nasopharynx. The hyoepiglotticus muscle confers stability to the most caudal aspect of the nasopharynx by preventing epiglottic retroversion.

Few investigations have been conducted to evaluate extrinsic factors relating to pharyngeal stability, but it is known that resection of the thyrohyoideus muscles leads to exercise-induced DDSP in some horses. The thyrohyoideus muscle extends from the thyroid cartilage to the thyrohyoid bone and is believed to be the most important muscle affecting elevation of the larynx as it moves the larynx rostrally. It has been proposed that laryngeal elevation enhances stability of the soft palate during exercise by moving the larynx rostrally.

Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Definition</th>
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<tbody>
<tr>
<td>DDSP</td>
<td>Dorsal displacement of the soft palate</td>
</tr>
<tr>
<td>EMG</td>
<td>Electromyography</td>
</tr>
<tr>
<td>MEA</td>
<td>Mean electrical activity</td>
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</tbody>
</table>

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and dorsally in relation to the hyoid apparatus.\(^1\) Another finding supporting the importance of the role of extrinsic structures is that transpharyngeal pressure (an estimate of increased resistance) increases in horses after partial myectomy of the sternothyroideus and sternohyoideus muscles.\(^2\)

Information about the activity of many relevant muscles of the extrathoracic airway in horses is limited because studies have focused more on activity of the intrinsic musculature. In 2 studies, investigators reported that intrinsic inspiratory activity of the hypoepiglotticus muscle increases during exercise\(^3\) and that the stylopharyngeus muscle has inspiratory-related activity and tonic activity that increases with an exercise intensity.\(^4\)

The study reported here focused predominantly on muscles extrinsic to the nasopharynx to provide additional information about their contribution in horses during exercise. The hypoglossal nerve innervates the genioglossus and geniohyoideus (suprahyoid or rostral hyoid) muscles.\(^5\) Contraction of the genioglossus, an extrinsic muscle of the tongue, causes a reduction in the dorsoventral diameter of the tongue, whereas the coordinated action of the genioglossus and geniohyoideus muscles causes the tongue to protrude, tenses the pharyngeal walls, and rostrally displaces the basihyoid bone to enlarge the diameter of the nasopharynx.\(^6,7\) However, computed tomographic analysis of horses with rostral displacement of the tongue manually induced to simulate rostral movement of the basihyoid bone and protrusion of the tongue yielded no measurable difference in nasopharyngeal diameter.\(^8\) The caudal hyoid (or infrahyoid) muscles include the sternothyroideus, sternohyoideus, and omohyoideus muscles, which all receive motor innervation from the first and second cervical nerves.\(^9\) Contraction of these muscles, which originate from the sternal manubrium and medial aspect of the shoulder fascia, results in caudal traction on the basihyoid bone and larynx. In humans and dogs, the opposing forces of the rostral and caudohyoid muscles sum to cause ventral displacement of the hyoid apparatus and increase the nasopharyngeal diameter.\(^10\) The hypoepiglotticus and thyrohyoid muscles are innervated by the hypoglossal nerve.\(^11\) Hypoepiglottic contraction causes the epiglottic cartilage to be pulled ventrally, which increases the dorsoventral diameter of the rima glottis.\(^12,13\) Activity of the thyrohyoid muscle is predominantly linked with elevation of the larynx during swallowing.\(^7,8,16\)

In humans, the suprahyoid and infrahyoid muscles are activated during the respiratory cycle via ongoing mechanoreceptor reflexes.\(^14,15\) Increasingly negative intraluminal pharyngeal pressures appear to recruit the pharyngeal muscles to stabilize the nasopharynx immediately before diaphragmatic and intercostal muscle activity.\(^16-21\) Activity of these rostral (suprahyoid) and caudal (infrahyoid) hyoid muscles has not been investigated in horses during exercise. We hypothesized that the genioglossus, geniohyoideus, hypoepiglotticus, omohyoideus, sternohyoideus, sternothyroideus, and thyrohyoid muscles have activity correlated with intensity of exercise and in phase with inspiration in exercising horses.

### Materials and Methods

**Animals**—Seven young adult (mean age, 4.7 years; range, 3 to 7 years) horses with a mean ± SD body weight of 422.7 ± 42.5 kg were used in the study. Horses comprised 5 Standardbreds and 2 Thoroughbreds (3 females and 4 castrated males). All horses were judged to be in good condition on the basis of results of a general physical examination. Dysfunction of the nasopharynx or larynx was not detected by videolaryngoscopic examinations performed at rest and during treadmill exercise. Horses were trained 5 d/wk on a treadmill for 2 months prior to the study. All procedures were approved by the Institutional Animal Care and Use committee at Cornell University.

**Procedures**—Horses were anesthetized and positioned in dorsal recumbency. After appropriate preparation for aseptic surgery, a 20-cm midline incision was made that extended from 10 cm rostral to the basihyoid bone to 5 cm caudal to the criocoid cartilage. Two fine-wire stainless-steel bipolar electrodes were surgically inserted into the hypoepiglotticus muscle and the genioglossus, geniohyoideus, omohyoideus, sternothyroideus, sternothyroideus, and thyrohyoid muscles on the left side of each horse. Wires were secured to their respective muscles with sutures. Electrodes were then tunneled through the subcutaneous tissues, exited the skin as a group in the left cervical area, and were secured to a custom-designed pocket sutured to the mane. Wires were identified according to their muscle insertion on the basis of the color of the wire casing and number of knots placed in the external portion.

All horses received broad-spectrum antimicrobials (trimethoprim-sulfadiazine; 30 mg/kg, PO, q 12 h) and phenylbutazone (1 mg/kg, PO, q 12 h) for 5 to 7 days after surgery. All horses were examined daily for evidence of complications or illness (signs of pain, swelling, or dysphagia) and allowed a period of 1 to 4 weeks after surgery before resumption of treadmill exercise.

**Experimental design**—After insertion of electrodes into selected extrinsic nasopharyngeal muscles, horses were exercised on a high-speed treadmill. Each horse performed an incremental speed test during which EMG recordings, gait frequency, and static pharyngeal pressure measurements were obtained. For each exercise trial, the treadmill was started at time 0, accelerated to 4 m/s, and maintained at that speed for 4 minutes. The treadmill was then accelerated to 6 m/s and maintained at that speed for 1 minute. Each subsequent minute, the treadmill was accelerated by 1 m/s until the horse was no longer capable of maintaining its position near the front of the treadmill. Horses were provided a rest period of at least 3 days to allow recovery before any subsequent exercise trial.

Electromyographic signals from the extrinsic muscles of the hyoid apparatus were processed through a sixth-order Butterworth filter (common mode rejection ratio, 90 dB; band pass, 50 to 5,000 Hz), amplified,\(^9\) rectified, and processed to yield a moving-time-averaged (time constant, 90 dB; band pass, 50 to 5,000 Hz) value. Raw and moving-time-averaged EMG signals were displayed on a thermal array recorder\(^a\) and recorded on a 16-channel digital recorder.\(^b\) The moving-time-averaged EMG was...
quantified by use of a method described elsewhere. Briefly, the digitized area of the moving-time-averaged signal was divided by the duration of activity to define the raw MEA. This value was then adjusted by dividing each signal by its appropriate gain (which had been used earlier to amplify the signal) to define the adjusted MEA.

Pharyngeal pressures were measured with a polytetrafluoroethylene catheter (inside diameter, 1.3 mm), which was positioned at the rostral aspect of the nasopharynx by use of videolaryngoscopy. The catheter was attached to a differential pressure transducer referenced to atmospheric pressure and calibrated at 0 and 50 cm H₂O.

To determine stride frequency via foot plant, an accelerometer* was secured to the lateral aspect of the left metacarpal bone. Analogue data from the pharyngeal catheter and accelerometer were digitized, displayed, and streamed into a disk at 64 Hz by use of a customized data-acquisition program. Simultaneously, the data were sent to the thermal array recorder (paper speed, 25 mm/s) to enable overall correlation of data.

Data analysis—Data were analyzed at the end of each exercise intensity interval. Twenty consecutive breaths selected during each speed interval were digitized. Pressure traces were used to determine mean and peak inspiratory and expiratory pressures. To standardize MEA data among horses and trials, adjusted MEA was expressed as a percentage of the value obtained at an exercise intensity of 6 m/s in the treadmill trials. The relationship of EMG activity with phase of the respiratory cycle was determined by comparing pharyngeal pressure waveforms with the moving-time-averaged EMG tracings generated by the thermal array recorder at maximal exercise intensity. Frequency analysis was performed by calculating the number of breaths, foot plants, and EMG electrical peaks during a specific time period as determined by thermal array tracings. Maximal exercise intensity measurements were obtained at the highest speed achieved by each horse (12 to 14 m/s).

Statistical software was used to analyze the associations of speed and pharyngeal pressure with muscle EMG measurements by use of mixed linear models. A separate model was used for each muscle. The response variable was the EMG measurements for the muscle expressed as a percentage of the value obtained for the exercise intensity of 6 m/s. The explanatory variables were speed (a continuous variable [8, 9, 10, 11, 12, 13, and 14 m/s, and then adjusted to values of 2, 3, 4, 5, 6, 7, and 8 m/s [ie, the difference from a speed of 6 m/s]), expiratory pressure (actual measurement as a continuous variable), and inspiratory pressure (actual measurement as a continuous variable). Horse and interactions of horse with explanatory variable main effects were included in the model as random effects with a variance component covariance structure. Pressure terms were removed from the model in a backward stepwise approach, with a value of P < 0.05 required to remain in the model; in addition, the horse X pressure interaction was removed when the main effect for pressure was not significant. Speed was retained as an explanatory variable in all models. Model assumptions were assessed by evaluating the distribution of the residuals and plotting residuals versus predicted values. Overall, the models appeared to be adequate; however, a few irregularities, such as skewed distributions of residuals and outlier data points, were detected. For all statistical analyses, values were considered significant at P ≤ 0.05.

Results

Animals and data collection—Electrodes were successfully inserted in all horses, and all horses completed the necessary training program and achieved a sufficient degree of fitness for the exercise protocol. Because necessary recordings were not obtained for all muscles during all exercise trials, multiple trials and recordings were needed to complete measurements for all 7 muscles; 4 horses required 2 trials, and 1 horse required 3 trials because data for at least 1 muscle (range, 1 to 3 muscles) were not obtained during an exercise trial. When > 1 exercise trial was required to obtain data for a muscle on a particular horse, the mean MEA was used. All 7 horses had complete data sets for the pharyngeal and accelerometer data. The life span of EMG wires varied among horses, so the actual sample size for each muscle was 7 for the geniohyoideus, sternothyroideus, and sternothyroidus muscles; 6 for the hyoepiglotticus, omohyoideus, and thyrohyoideus muscles; and 5 for the genioGLOSSUS muscle. All horses reached and completed a maximal exercise intensity of 12 m/s, 6 completed 13 m/s, and 2 completed 14 m/s. At maximal exercise intensity, mean ± respiratory rate was 135 ± 7 breaths/min (range, 120 to 142 breaths/min), which was identical to the gait frequency. Also at maximal exercise intensity, the heart rate was 223 beats/min.

Table 1—Mean ± SD and median values for selected muscles of the hyoid apparatus in 7 clinically normal horses exercising at maximal exercise intensity (12 to 14 m/s).

<table>
<thead>
<tr>
<th>Muscle</th>
<th>MEA (%)*</th>
<th>PI (cm H₂O)</th>
<th>Pe (cm H₂O)</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Mean ± SD</td>
<td>Median</td>
<td>Mean ± SD</td>
</tr>
<tr>
<td>Geniohyoideus (7)</td>
<td>153.88 ± 51.80</td>
<td>149.45</td>
<td>–17.84 ± 5.22</td>
</tr>
<tr>
<td>GenioGLOSSUS (9)</td>
<td>141.60 ± 77.63</td>
<td>119.52</td>
<td>–17.14 ± 4.46</td>
</tr>
<tr>
<td>Hyoepiglotticus (6)</td>
<td>176.63 ± 108.78</td>
<td>143.08</td>
<td>–17.70 ± 4.79</td>
</tr>
<tr>
<td>Omohyoideus (6)</td>
<td>121.19 ± 52.44</td>
<td>109.18</td>
<td>–16.62 ± 4.89</td>
</tr>
<tr>
<td>Sternohyoideus (7)</td>
<td>181.14 ± 162.49</td>
<td>114.62</td>
<td>–16.82 ± 4.29</td>
</tr>
<tr>
<td>Sternothyroideus (7)</td>
<td>134.06 ± 38.61</td>
<td>128.29</td>
<td>–17.30 ± 4.70</td>
</tr>
<tr>
<td>Thyrohyoideus (6)</td>
<td>180.53 ± 197.44</td>
<td>115.85</td>
<td>–17.47 ± 4.39</td>
</tr>
</tbody>
</table>

Numbers in parentheses represent sample size. *Values for MEA are expressed as a percentage of the activity measured at an exercise intensity of 6 m/s. PI = Peak inspiratory pharyngeal pressure. Pe = Peak expiratory pharyngeal pressure.
The geniohyoideus muscle had only expiration-related muscle activity, with peak activity immediately preceding inspiration, as determined on the basis of analysis of pharyngeal pressure tracings (Figure 1). Notice that the MEA is predominantly during the expiratory phase of respiration (E), with peak activity immediately preceding inspiration (I). The EMG MEA frequency was associated with the respiratory rate and gait frequency in a 1:1:1 ratio for all muscles. Intensity of EMG activity of the genioglossus, geniohyoideus, and hyoepiglotticus muscles increased significantly with increasing treadmill speed (Figure 2). However, the omohyoideus, sternohyoideus, sternothyroideus, and thyrohyoideus muscles did not have a significant increase in EMG activity with exercise at speeds faster than 6 m/s (Figure 3). Peak inspiratory and peak expiratory pharyngeal pressure became significantly more negative and more positive, respectively, as treadmill speed increased in all trials. Although in general there was a phasic correlation of muscle activity immediately preceding inspiration, there was a significant association between MEA activity and an increased absolute value of pharyngeal expiratory pressure detected for the geniohyoideus and hyoepiglotticus muscles only (Table 2). None of the other muscles had a significant association between intensity of MEA and absolute peak inspiratory or peak expiratory pressure.

**Discussion**

When interpreting results of the study reported here, technical difficulties encountered in recording all 7 muscles simultaneously during strenuous exercise should be considered. At rest, placement of the electrodes in a cloth bag loosely attached to the mane of a horse protected the electrodes and minimized inadvertent damage to the wires. One or more electrodes became disconnected during exercise, which necessitated >1 trial to successfully record all muscles of each horse. This technical issue was difficult to resolve because we intentionally maintained the electrode-connector site as the weakest point to eliminate electrode breakage by preventing disruption forces (ie, forces resulting from changes in a horse’s position on the treadmill) to be transmitted past the connectors to the electrode wires. The use of longer connector wires and stretching the cord that secured them to a horse’s harness were helpful in preventing strain on the connector-wire interface. Determining the mean values for data may have prevented identification of small differences but should have minimized the effect of outlier data points. We standardized data collected to the lowest incremental speed (6 m/s). This allowed comparisons of the remaining 2 horses, activity was primarily during expiration, but there was some low amount of activity extending into the inspiratory phase. In contrast, most of the activity for the hyoepiglotticus and sternothyroideus muscles was during the inspiratory phase of the respiratory cycle, but it was maintained at a low amount of constant activity during both phases of respiration in all horses, except one. In all horses, activity of the omohyoideus muscle encompassed both phases of the respiratory cycle, and it maintained a low amount of tonic activity.

MEA activity—The geniohyoideus muscle had expiratory-related activity, with peak activity immediately preceding inspiration, as determined on the basis of analysis of pharyngeal pressure tracings (Figure 1). These findings were consistent in 6 of 7 horses; the remaining horse had activity during both phases of respiration. Most of the activity for the sternohyoideus muscle was during expiration, with peak activity at end of expiration immediately prior to onset of inspiration in all horses. The genioglossus muscle also had primarily expiration-related activity; with major electrical peaks preceding inspiration; however, 2 horses had activity during both phases of respiration. In 4 horses, the thyrohyoideus muscle had only expiration-related muscle activity, with the muscle at complete rest during inspiration. In the remaining 2 horses, activity was primarily during expiration, but there was some low amount of activity extending into the inspiratory phase. In contrast, most of the activity for the hyoepiglotticus and sternothyroideus muscles was during the inspiratory phase of the respiratory cycle, but it was maintained at a low amount of constant activity during both phases of respiration in all horses, except one. In all horses, activity of the omohyoideus muscle encompassed both phases of the respiratory cycle, and it maintained a low amount of tonic activity.

The EMG MEA frequency was associated with the respiratory rate and gait frequency in a 1:1:1 ratio for all muscles.
speed and respiratory pressure with EMG activity measured by MEA but did not allow extrapolation to resting data. In humans and laboratory animals, the size and stability of the pharynx are achieved through coordinated action between the intrinsic nasopharyngeal and tongue muscles and extrinsic tongue and hyoid muscles, 13,15,23-25 Specifically, control of pharyngeal dilation is mediated predominantly by extrinsic muscles of the tongue11,26-29 and by muscles that influence the position of the hyoid bone.13,23-25 Therefore, we hypothesized that the extrinsic tongue muscles (genioglossus muscle) and muscles affecting the position of the hyoid apparatus in horses would also enhance stability of the nasopharynx. We determined that all the muscles studied (genioglossus, geniohyoideus, hyoepiglotticus, omohyoideus, sternohyoideus, sternothyroideus, and thyrohyoideus muscles) had activity in phase with respiration (a 1:1 ratio of breaths:EMG waveform) during strenuous exercise. It must be pointed out that it was not possible to determine whether MEA association was with gait frequency or the respiratory system because the respiratory system because the respiratory rate and gait frequency were also associated as a 1:1 ratio. Interestingly, only muscles expected to move the hyoid bone in a rostral direction (genioglossus and geniohyoideus muscles) and the muscle believed to increase nasopharyngeal diameter (hyoepiglotticus muscle) had activity that increased significantly with an increase in exercise. Muscles caudal to the hyoid apparatus (omohyoideus, sternohyoideus, sternothyroideus, and thyrohyoideus muscles), which are expected to move the hyoid bone in a caudal direction, had no further progressive increase in activity for speeds > 6 m/s, as measured by MEA. Stimulus of exercise-induced enhancement of muscular activity of the omohyoideus, sternohyoideus, sternothyroideus, and thyrohyoideus muscles appeared to be independent of airway pressure or exercise intensity. This is consistent with results in rats30 in which increased tonic muscular activity for the omohyoideus and sternohyoideus muscles was associated with exercise but without phasic recruitment during any phase of the respiratory cycle.

The significant positively correlated increase in muscle activity with increased exercise intensity in the rostral hyoid musculature of horses is consistent with the enhancement of airway patency in other mammals for various conditions as a result of activity of the same muscles. In humans, stimulation of the hypoglossal nerve, which innervates the suprahyoid muscles (genioglossus and geniohyoideus as well as the styloglossus and hyoglossus muscles), can increase the diameter of the nasopharynx and decrease airflow resistance and is an alternative treatment method for obstructive sleep apnea.11,13,16,23-26,33 The genioglossus muscle is believed to mediate the major effect for maintaining airway stability.12,13 In cats, rabbits, and dogs, electrical stimulation of the geniohyoideus muscle led to a significant decrease in resistance of the upper airway during partial obstruction, whereas stimulation of the genioglossus muscle resolved total airway obstruction.11,23,34 The effect of imposing negative pressures on the airway mediates a reflex activation, as determined on the basis of results of EMG of these muscles.19,20,33,35 In addition, this mechanoreceptor reflex is active during normal breathing with physiologic pressure changes.35 Hypoxic hypercapnia increases EMG activity of the genioglossus muscle as well as the soft palate and expiratory abdominal muscles.37,38 Additionally, hypoxic normocapnic episodes can evoke a prolonged augmentation of inspiratory motor output (referred to as long-term facilitation) from the hypoglossal nerve.38 Therefore, increases in muscle activity may be a compensatory mechanism to maintain upper airway patency during hypoxic episodes.

Figure 3—Mean ± SE MEA of the omohyoideus muscle (A), sternohyoideus muscle (B), sternothyroideus muscle (C), and thyrohyoideus muscle (D) for 7 clinically normal horses exercising at various exercise intensities (ie, speed of the treadmill).

Table 2—Summary of P values from a mixed-linear model analysis between MEA activity and the absolute value of pharyngeal pressures obtained for selected muscles of the hyoid apparatus in 7 clinically normal horses exercising at maximal exercise intensity (12 to 14 m/s) on a high-speed treadmill.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Genioglossus (5)</th>
<th>Geniohyoideus (7)*</th>
<th>Hyoepiglotticus (6)*</th>
<th>Omohyoideus (6)</th>
<th>Sternothyroideus (7)</th>
<th>Sternothyroideus (7)</th>
<th>Thyrohyoideus (6)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed</td>
<td>0.02</td>
<td>0.01</td>
<td>0.03</td>
<td>0.10</td>
<td>0.48</td>
<td>0.17</td>
<td>0.18</td>
</tr>
<tr>
<td>Pi</td>
<td>0.17</td>
<td>0.85</td>
<td>0.99</td>
<td>0.33</td>
<td>0.18</td>
<td>0.13</td>
<td>0.18</td>
</tr>
<tr>
<td>Pe</td>
<td>0.70</td>
<td>0.02</td>
<td>0.04</td>
<td>0.65</td>
<td>0.21</td>
<td>0.81</td>
<td>0.30</td>
</tr>
</tbody>
</table>

Values were considered significant at P < 0.05.

*A significant (P < 0.05) association was detected between MEA activity and increased absolute value of pharyngeal pressures for this muscle.

See Table 1 for remainder of key.
activity would be expected during exercise when there is an increase in negative airway pressure and hypoxemia in horses exercising at maximal intensity. We determined that activity of the genioglossus and geniohyoideus muscles peaked immediately prior to the onset of inspiration, which suggested a role in stabilizing the pharynx in preparation for upcoming negative pressures, similar to those for EMG of the diaphragm in which activity precedes onset of inspiration. Unexpectedly, EMG activity of the geniohyoideus muscle, although in phase with inspiration, was significantly associated with increased expiratory activity (but not inspiratory) pharyngeal pressures during exercise. The reason for this finding is not known.

Categorization of the function and activity of the hyoepiglottic muscle does not lend itself easily to the typical rostral and caudal hyoid groupings. There is a hyoepiglottic ligament in humans, rather than a hyoepiglottic muscle. In tracheostomized anesthetized dogs subjected to carbon dioxide infusion in inspired gases, the hyoepiglottic muscles have both phasic inspiratory and expiratory activity. This activity of the hyoepiglotticus muscle is mediated by laryngeal detection of negative pressure and eliminated by transecting the internal branch of the recurrent laryngeal nerve. Similarly, the hyoepiglotticus muscle in clinically normal horses during exercise has phasic inspiratory and expiratory EMG activity; however, only the inspiratory portion increases significantly with an increase in treadmill speed. The increase in activity correlated with treadmill speed results in an increase in the length and area of the laryngeal opening (aditus laryngis), which thereby decreases resistance to airflow. Similar to the result in another study, most of the activity for the hyoepiglotticus muscle in the horses reported here was in phase with inspiration, and the activity extended through both the inspiratory and expiratory phases. Conversely, EMG activity of the hyoepiglotticus muscle increased significantly with higher expiratory pharyngeal pressures. Because electrical activity straddles inspiration and expiration, inspiratory quantification was not separated from expiratory activity. Indeed, conclusions about the mechanism of action triggered by increased expiratory pressure would be speculative, given that electrical activity likely precedes or is preparatory to pressure changes. It may be possible that the afferent sensory loop for activity of the hyoepiglotticus muscle in horses is driven by expiratory pressure.

The infrahyoid muscles, including the omohyoides, sternohyoideus, sternothyroideus, and thyrohyoideus muscles, are responsible for control of the larynx. On the basis of results of experimental preparations in dogs, it has been proposed that the opposing forces of the rostral and caudal hyoid muscles in humans sum to cause ventral displacement of the hyoid apparatus and increase the nasopharyngeal diameter. Results of a study in horses also support the importance of activity of the sternohyoideus and sternothyroideus muscles in maintaining nasopharyngeal stability. However, in the study reported here, no additional evidence of increased muscular contraction with exercise was detected by statistical analysis or visual inspection of the data. Perhaps the activity of these muscles in horses is maximally stimulated with onset of exercise, even a low-intensity exercise. This would suggest that the roles of the sternohyoideus and sternothyroideus muscles in maintaining airway patency during exercise are modest. This finding in horses would be consistent with the finding in dogs in which it was revealed that function of the sternohyoideus and sternothyroideus muscles in maintaining or improving airway patency is minimal, if any. In one of those studies, activity of all the hyoid muscles was increased by hypercapnia, except for activity of the sternothyroideus muscle. In the other of those studies, electrical stimulation of the sternothyroideus and sternothyroideus muscles in anesthetized dogs with obstruction of the extrathoracic airways resulted in no significant change in extrathoracic airway resistance. In the study in horses reported here and in a study in dogs, there was phasic activity of the thyrohyoideus muscle with respiration. However, in our study, the lack of a significant increase in activity of the thyrohyoideus muscle with increasing exercise intensity was unexpected. Indeed, lack of function for the thyrohyoideus muscle has been associated with decreased nasopharyngeal patency in horses with DDSP. Furthermore, increased activity of the thyrohyoideus muscle was detected in dogs with hypercapnia, which indicates that this muscle plays a role in maintaining airway patency. One explanation is that there is an effect of the thyrohyoideus muscle that was not detected in the horses of our study because the sample size was too small. Indeed, by inspection, it is possible that the high variation of the data at the highest exercise intensity prevented detection of an effect of the thyrohyoideus muscle (Figure 3). Nevertheless, because only the activity of the muscles caudal to the hyoid bone failed to have an effect during increased exercise, it is possible that the most important factors for airway stability in horses during exercise is rostral displacement of the hyoid and larynx. This would be consistent with the hypothesis in sleeping humans that airway obstruction (ie, sleep apnea) is attributable to ventral descent of the larynx and the reason that most of the studies in humans and other species have revealed an improvement in airway patency after stimulation or activity of the muscles rostral to the basihyoid bone. Results of the study reported here confirmed that in horses with normal function of the nasopharynx and larynx, rostral and caudal hyoid muscles have activity during exercise in phase with respiration. Furthermore, muscles expected to increase the diameter of the pharynx or rima glottidis (genioglossus, geniohyoideus, and hyoepiglotticus muscles) have increasing activity with increases in exercise intensity, whereas the caudal hyoid muscles have electrical activity that is stable during exercise regardless of the exercise intensity. This is similar to the situation in humans in which activity of the genioglossus and geniohyoideus muscles appears to be most important for maintaining airway patency (both patency and airflow collapsibility) during sleep and in the pathophysiologic processes of obstructive sleep apnea.
Determining muscle activity in horses with naturally developing DDSP is needed to provide a better understanding of the relative contribution of each extrinsic muscle, if any, to airway stability during exercise.

References


