The equine larynx provides a conduit for airflow during respiration and functions in phonation and airway protection while swallowing. Airway movement is influenced by contraction of specific intrinsic adductor and abductor muscles that serve to alter the size of the laryngeal lumen at its narrowest point, the rima glottidis. The bilateral CAD muscles are the sole laryngeal abductors in horses. Their contraction moves the arytenoid cartilages out of the cricoid cartilage lumen, dilating the rima glottidis.

Horses at peak exercise intensity have exceptionally large minute ventilations (approx 1,400 L/min in Thoroughbreds). A common cause of equine airway obstruction is recurrent laryngeal neuropathy, an idiopathic disorder that predominately affects the left recurrent laryngeal nerve, resulting in neurogenic atrophy of the CAD muscle and compromised arytenoid cartilage abduction. Diminished athletic performance in affected horses is associated with reduced inspiratory airflow and increased inspiratory resistance. Severely affected horses require surgical intervention, with prosthetic laryngoplasty being the preferred technique.

Three-dimensional biomechanics of simulated laryngeal abduction in horses

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Objective—To investigate the influence of simulated contraction of the cricoarytenoideus dorsalis (CAD) muscle on the 3-D motion of the arytenoid cartilage.

Sample Population—5 larynges from equine cadavers.

Procedures—Serial computed tomographic scans of each larynx were conducted at 7 incremental forces simulating contraction of medial, lateral, and combined bellies of the left CAD muscle. Three-dimensional reconstruction of radiopaque markers placed at anatomic landmarks on the left arytenoid and cricoid cartilages enabled quantification of marker displacement according to a Cartesian coordinate system. Rotation (roll, pitch, and yaw) of dorsal and ventral arytenoid planes was calculated relative to a plane formed by the coordinates of 3 markers on the cricoid cartilage by use of Euler angles.

Results—Displacement and rotational data showed that rocking motion occurs throughout arytenoid abduction and most of the rotational component is attributable to pitch; greater pitch was associated with action of the lateral belly. Roll of the ventral arytenoid plane was principally associated with action of the medial belly, which counteracted the tendency of the arytenoid cartilage to rotate medially into the rima glottidis lumen. The distance between markers on the arytenoid cartilage was not constant during contraction because of slight deformation of the corniculate process of the arytenoid cartilage, therefore indicating that the arytenoid cartilage is not a rigid body during abduction.

Conclusions and Clinical Relevance—Arytenoid cartilage abduction was dependent on the rocking motion elicited by the lateral belly of the CAD muscle; therefore, laryngoplasty suture placement should mimic the action of the lateral, rather than the medial, muscle belly. (Am J Vet Res 2010;71:1003–1010)
been demonstrated that the equine CAD muscle is divided into medial and lateral bellies, each with a different line of action.\textsuperscript{11} The analogous PCA muscle in humans also has 2 bellies,\textsuperscript{12} but 3 bellies have been identified in dogs.\textsuperscript{13} Each CAD-PCA muscle belly has different histologic and mechanical properties\textsuperscript{14,15}\textsuperscript{15} and is innervated by a discrete nerve branch.\textsuperscript{11,15,16}

The equine CAJ is a synovial articulation with a thin, loose capsule.\textsuperscript{17} Oval concave facets at the arytenoid cartilage base articulate with corresponding convex facets at the rostral border on either side of the cricoid cartilage lamina.\textsuperscript{17} The cricoarytenoid ligament supports the ventromedial aspect of the joint capsule,\textsuperscript{17} stabilizing the arytenoid cartilages as they move.

In the study reported here, we aimed to investigate the 3-D characteristics of left arytenoid cartilage motion during abduction resulting from simulated muscle contraction of the equine CAD muscle. Three-dimensional reconstruction of the position of radiopaque markers placed on the left arytenoid and dorsal cricoid lamina allowed calculation of marker displacement and left arytenoid rotation. In addition, we aimed to determine whether forces simulating contraction of the medial and lateral bellies of the CAD muscle cause different arytenoid motion. To our knowledge, a comprehensive 3-D description of arytenoid cartilage motion and the influence of the medial and lateral bellies of the equine CAD muscle on this motion have not previously been described.

Materials and Methods

Sample populations—Five larynges were harvested from adult Thoroughbreds aged between 15 and 30 years (mean, 23.6 years). Horses were euthanatized by lethal injection for reasons unrelated to the upper respiratory tract, and the study protocol was approved by the Ethics Committee of the Royal Veterinary College. The larynges were of normal symmetry and morphology on gross inspection and were stored at 4°C in a 2% 2-phenoxyethanol solution\textsuperscript{18} to preserve tissue suppleness.\textsuperscript{18} Experiments were performed within 3 to 5 days of harvest, and the larynges were warmed to room temperature (approx 20°C) before use.

Laryngeal preparation and mounting—The extrinsic laryngeal musculature was removed, taking care to preserve the CAJs, ligamentous attachments, and CAD muscles. The most rostral cartilaginous tracheal ring was used for mounting, but all others were removed. The morphology of the CAD muscles and their attachment to the muscular process of the arytenoid cartilage were documented prior to dissection.

Orientation and length of the CAD muscle fascicles were quantified ultrasonographically by use of a 10-MHz linear transducer.\textsuperscript{9} Medial and lateral bellies of both right and left CAD muscles were measured at 3 sites from their center of origin to their insertion on the muscular process of the arytenoid cartilage and a mean calculated. The main adductor muscles (cricothyroideus, cricoarytenoideus lateralis, ventricularis, and arytenoideus transversus) were transected. The medial and lateral bellies of the CAD muscle were dissected away from the cricoid lamina on both sides, taking care to preserve their fascial planes of attachment to the muscular process of the arytenoid cartilage. The muscle bellies from each side were weighed individually.\textsuperscript{9} Water displacement was used to measure the volume of each muscle belly.

To ensure consistency, laryngeal positioning, marker and suture placement, and tensioning were performed by the same person (JDP). Each larynx was suspended from 2 connected retorts stands through rigid attachment to their cricoid lamina, thereby enabling precise and repeatable positioning of each larynx. The assembly was positioned in a CT scanner.\textsuperscript{3} Twelve radiopaque 3-mm-diameter spherical markers were placed at identical positions on and around each larynx (Figure 1). Three of the radiopaque markers (ie, fixed markers) were used to determine each larynx's fixed position relative to the CT scanner table. Markers were sutured to the DorC, MidC, and VenC and the left MPA. Three markers (each 1 cm apart) were placed adjacent to the median crest and rostral border on the dorsal surface of the right cricoid lamina. Ten of the 12 markers were subsequently used for analysis.

Two luer lock adapters were secured to the dorsal surface of the left cricoid lamina at the center of origin of each muscle belly, orientated perpendicularly to each muscle's longitudinal fiber plane. A 0.65-mm-diameter monofilament nylon suture\textsuperscript{1} was placed through the tendinous insertion of the medial and lateral bellies of the CAD muscle on the MPA and secured with a surgeon's knot. One free end of the suture was passed through the luer lock adapter to represent contraction of the medial muscle belly fibers, and the other free end was passed through the luer lock adapter representing contraction of the lateral muscle belly fibers.

Experimental design—A portable force meter\textsuperscript{6} was used to apply suture tension in the direction of the boundary between the origins of medial and lateral muscle bellies, until maximum arytenoid cartilage abduction was achieved. The mean force of 3 maximum abductions (ie, \(F_{\text{max}}\)) was calculated.

Muscle morphology—Including volume, fiber length, fiber angle, and PCSA greatly influences muscle function.\textsuperscript{19} The PCSA is proportional to the force potential of the muscle,\textsuperscript{20} and is often used when calculating maximal muscle force and the relative contribution of specific muscles to total joint torque.\textsuperscript{21} The formula for PCSA is muscle volume divided by fiber length multiplied by the cosine (fiber angle). However, fibers of the CAD muscle are arranged in parallel; hence, the cosine (fiber angle) is 1 and can be ignored. Percentage contribution of the force calculated for maximal abduction of the arytenoid cartilage from the mediolateral (\(F_{\text{max\ mediolateral}}\)) muscle belly was determined as follows:

\[
F_{\text{max\ mediolateral}} = \frac{F_{\text{max}} \times \text{PCSA}_{\text{medial}}}{\text{PCSA}_{\text{medial}} + \text{PCSA}_{\text{lateral}}}
\]

Similarly, the amount of force required for maximal abduction of the arytenoid cartilage from the lateral muscle belly was determined. The amount of force calculated for each muscle belly's contribution to maximal abduction of the left arytenoid was divided into 6 increments (ie, \(F_{1,2,3,4,5,6}\)) that were used subsequently to examine inter-
mediate degrees of abduction (ie, a medial muscle belly with maximal abduction force of 6 N would have 1 N, 2 N, 3 N, 4 N, 5 N, and 6 N of force applied). Measurements at zero force (ie, $F_{I0}$) were also recorded so that for each muscle belly, 7 positions were evaluated.

Three-dimensional biomechanical modeling—Transverse computed tomographic images of each larynx were acquired at each amount of force for medial, lateral, and combined muscle bellies (randomized for muscle belly) with a slice thickness and slice distance of 1.5 mm (120 kV, 100 mA). Three-dimensional reconstructions of the larynges were generated by segmenting the images by use of grayscale thresholding followed by surface wrapping on the basis of polynomial meshing. A local Cartesian coordinate system was defined with the most rostral and medial cricoid marker as the origin. The coordinates of the center of each spherical marker were determined for each evaluation within this system, thus allowing for correction for marker movement in space.

Marker displacement on simulated contraction of medial, lateral, and combined muscle bellies was calculated by subtracting their coordinates at $F_{I0}$ from their coordinates at each predetermined amount of force ($F_{In}$). Mean x, y, and z coordinate (lateral, dorsal, and caudal) displacement was calculated for these markers for the 5 larynges. The distance between coordinates of markers at MPA and DorC, MPA and MidC, DorC and MidC, MPA and VenC, and MidC and VenC was calculated by use of the Pythagorean theorem. The mean change in distance from $F_{I0}$ to $F_{In}$ was calculated for the 5 larynges.

Rotational movements of different parts of the larynx were expressed by use of Euler angles. All calculations were performed with custom-written software.1 Yaw rotation of the 3 fixed markers was used to compensate for yaw of the whole larynx. Rigid body motion was assumed for markers at MPA, DorC, and MidC (dorsal arytenoid plane) and for markers at MPA, MidC, and VenC (ventral arytenoid plane). The rotation of dorsal and ventral arytenoid planes relative to the reference frame formed by the 3 cricoid markers was calculated. This resulted in pitch, yaw, and roll rotations about x, y, and z axes, respectively (Figure 1). Changes in absolute roll, pitch, and yaw were calculated for the dorsal and ventral arytenoid planes for all applied forces, muscle bellies, and larynges by subtracting the roll, pitch, or yaw at $F_{I0}$ from the roll, pitch, or yaw at $F_{In}$. To adjust for variation in the maximal rotation of the left arytenoid between larynges, percentage maximal roll, pitch, and yaw was calculated for the dorsal and ventral arytenoid planes as follows:

$$\text{Maximal pitch} \% = 100 \times \frac{\text{absolute pitch at } F_{In}}{\text{absolute pitch at } F_{I0}\text{ combined}}$$

Cricoarytenoid joint disarticulation and arytenoid cartilage dissection—On completion of the CT
evaluations, the CAJs were disarticulated and the arytenoid cartilages dissected. Ligamentous attachments of the CAJ and anatomy of the articular facets were examined for normal morphology. The corniculate cartilage was manipulated to assess its elastic nature.

**Statistical analysis**—The effect of larynges, amount of force, and muscle bellies on absolute and relative rotational data of dorsal and ventral arytenoid planes; lateral, dorsal, and caudal displacement of markers at MPA, DorC, MidC, and VenC; and length change between markers at MPA, DorC, MidC, and VenC was evaluated by use of a multiple univariate ANOVA. One-way ANOVA was used to compare displacement data and absolute and relative rotational data between different muscle bellies and the length changes between different markers on the arytenoid. Values of $P < 0.05$ were considered significant.

**Results**

**Anatomy**—Findings on ultrasonography and dissections revealed that the CAD muscle was clearly divided into 2 bellies with separate origins and insertions. The medial muscle belly originated from the midline of the dorsal cricoid lamina and coursed laterally and obliquely to insert on the muscular process and dorsal surface of the arytenoid cartilage. The fan-shaped lateral muscle belly originated from the caudal border of the cricoid cartilage and attached, via a tendon of insertion, to the muscular process of the arytenoid. Separate medial and lateral bellies were sometimes poorly defined at the cricoid origin, but fascial separation was always clear at the arytenoid insertion of each belly. Additionally, the medial muscle belly had an extremely thin fascial attachment to the arytenoid muscular process and a second nontendinous insertion to the dorsal surface of the arytenoid cartilage. The lateral muscle belly consistently contained a well-defined fascial tendon of insertion on the dorsal aspect of the muscular process.

Left medial muscle bellies had smaller mean ± SD values (all larynges) than did left lateral muscle bellies for muscle fiber length (3.5 ± 0.4 cm vs 5.0 ± 0.5 cm), muscle belly mass (4.15 ± 1.389 g vs 5.60 ± 1.30 g), and muscle belly volume (4.05 ± 1.30 cm$^3$ vs 5.50 ± 1.12 cm$^3$). However, mean PCSAs calculated from these values for left medial and lateral muscle bellies were similar at 1.15 ± 0.31 cm$^2$ and 1.10 ± 0.15 cm$^2$, respectively. Mean force required to maximally abduct the left arytenoid cartilage was 15.2 ± 3.35 N (range, 12 to 20 N).

**Displacement by combined muscle bellies**—Force simulating the action of combined muscle

![Figure 2](image-url)
bellies caused large caudal displacement of the MPA (Figure 2). Slight dorsal and lateral displacements were also observed at the MPA. As this marker was placed closest to the CAJ, its motion best represents that of the arytenoid articular facet moving relative to its cricoid counterpart. Motion was referred from the MPA to the corniculate cartilage and consisted of large dorsal and lateral displacement of markers at MidC and VenC. Displacement of the marker at DorC was minimal in all directions. This combination of displacements suggests that rocking motion may be a feature of the cricoarytenoid articulation. After an initial large change in marker displacement, only gradual further displacement was evident at higher tensions.

Displacement by medial and lateral muscle bellies—Simulated muscle forces for medial and lateral muscle bellies caused different displacements of the arytenoid cartilage. Lateral belly simulated tension generated greater lateral displacement of the arytenoid than medial belly tension and the former created significantly greater displacement of markers at MPA (P < 0.001), DorC (P < 0.001), and MidC (P = 0.001). Small medial displacement of the MPA was associated with the medial muscle belly. Lateral muscle belly simulated tension also caused significantly (P = 0.017) greater caudal displacement at the MPA (Figure 2). Dorsal displacement of the MPA generated by medial muscle belly simulated tension was similar to that resulting from the action of combined muscle bellies. Although the dorsal displacement of the MPA generated by simulated medial muscle belly tension was small, it was significantly (P < 0.001) higher than the minimal dorsal displacement associated with the lateral belly. Displacement associated with combined belly simulated tension was less than the sum of the mean displacements associated with medial and lateral muscle bellies, suggesting that the action of both bellies simultaneously is not additive but slightly antagonistic.

Length changes by combined muscle bellies—On combined muscle belly simulated tension, there was significantly (P < 0.001) greater distance change between the markers at MPA and DorC than between the other markers on the left arytenoid. At FI, the distance between the markers at MPA and DorC increased by 3.23 ± 1.25 mm, representing a 7.9% overall increase in length and indicating that deformation of the cartilage had occurred.

Rotational data—Simulated tension in the combined muscle bellies generated the highest mean absolute change in roll, pitch, and yaw in both the dorsal and ventral arytenoid planes, compared with that of individual muscle bellies. Of the 3 rotational movements, pitch contributed the most toward arytenoid cartilage rotation, followed by roll and yaw, respectively (Table 1), and greater pitch and reduced roll were observed in the ventral, compared with the dorsal, arytenoid plane. These movements likely reflect the differing orientation of the rotational planes relative to the x, y, and z axes.

Results for simulated tension in the medial and lateral muscle bellies were similar, except for roll of the ventral arytenoid plane and pitch of the dorsal arytenoid plane. Mean percentage maximal roll of the ventral arytenoid plane was significantly (P = 0.013) greater for the medial muscle belly tension, compared with lateral belly tension (Figure 3), while mean percentage maximal pitch of the dorsal arytenoid plane was significantly (P = 0.001) greater for the lateral belly tension than for the medial belly tension (Figure 4). There was considerable overlap between medial and lateral muscle bellies for mean percentage maximal roll and pitch in the dorsal and ventral arytenoid planes, respectively. Increasing tensions generated an initial rapid increase in roll and pitch in both dorsal and ventral arytenoid planes, followed by a gradual increase at higher forces.

CAJ disarticulation—After disarticulating the CAJ, the cricoarytenoid ligament was visible bridging the ventromedial aspect of the joint in a caudolateralrostomedial direction, and in all larynges, it attached the inner cricoid lamina to the medial aspect of the arytenoid cartilage, ventral to the cricoarytenoid articulation. In all larynges the arytenoid cartilages were of the same basic shape, including a horn-shaped process on the inner cricoid lamina to the medial aspect of the arytenoid cartilage, ventral to the cricoarytenoid articulation. In all larynges the arytenoid cartilages were of the same basic shape, including a horn-shaped process on the rostral corniculate process. Deformation of the dorsal aspect of the corniculate cartilage was possible with minimal pressure (Figure 5).
In this study, the lateral belly of the equine CAD muscle was found to be more influential in producing arytenoid abduction, as was found in a previous study. The PCSA of the medial and lateral muscle bellies was found to be similar in the present study. Muscle force generation capacity is directly related to PCSA, thus suggesting the force output of the 2 bellies is similar during arytenoid abduction, assuming the same motor unit size and degree of recruitment. Differences were, however, seen in muscle mass, volume, and fiber length between the 2 bellies. The lateral muscle belly had a longer mean fiber length, which enables greater shortening during contraction and may therefore explain the greater range of arytenoid movement observed.

Type 2 (fast-twitch) fibers predominate in both the medial and lateral bellies of the equine CAD muscle, as in the canine PCA muscle. The canine oblique belly has an increased proportion of type 2 fibers in comparison to the other 2 bellies, which has been proposed to be a result of the belly's function in deep rapid breathing during exercise. Although the lateral muscle belly is the most influential in arytenoid cartilage abduction, similar type 2 fiber distribution within the medial belly may be a result of the medial belly's role in externally rotating the arytenoid cartilage about the rostrocaudal axis to prevent the vocal process of the arytenoid cartilage from narrowing the rima glottidis during the medial rocking motion associated with the lateral muscle belly. Furthermore, the lateral belly contains relatively more type 1 fibers than does the medial belly in horses. We

**Table 1**—Mean ± SD (range) values for the absolute change in roll, pitch, and yaw of the dorsal arytenoid plane and ventral arytenoid plane during abduction at F1 for medial, lateral, and combined muscle bellies.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Roll (°)</th>
<th>Pitch (°)</th>
<th>Yaw (°)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Dorsal arytenoid plane</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medial muscle belly</td>
<td>21.00 ± 7.84a</td>
<td>−24.18 ± 11.45a</td>
<td>11.62 ± 9.72a</td>
</tr>
<tr>
<td></td>
<td>(8.41 to 27.38)</td>
<td>(−37.93 to −7.96)</td>
<td>(−2.48 to 22.37)</td>
</tr>
<tr>
<td>Lateral muscle belly</td>
<td>21.02 ± 4.32a</td>
<td>−31.46 ± 9.41a</td>
<td>12.67 ± 10.25a</td>
</tr>
<tr>
<td></td>
<td>(14.79 to 26.46)</td>
<td>(−38.70 to −15.27)</td>
<td>(−1.41 to 21.70)</td>
</tr>
<tr>
<td>Combined muscle bellies</td>
<td>29.15 ± 5.68a</td>
<td>−39.36 ± 9.97a</td>
<td>16.12 ± 9.43a</td>
</tr>
<tr>
<td></td>
<td>(19.73 to 33.93)</td>
<td>(−50.80 to −27.95)</td>
<td>(3.57 to 26.71)</td>
</tr>
<tr>
<td><strong>Ventral arytenoid plane</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medial muscle belly</td>
<td>15.11 ± 5.44a</td>
<td>−43.22 ± 16.32a</td>
<td>3.71 ± 21.12a</td>
</tr>
<tr>
<td></td>
<td>(7.56 to 22.74)</td>
<td>(−62.85 to −17.61)</td>
<td>(−20.14 to 30.95)</td>
</tr>
<tr>
<td>Lateral muscle belly</td>
<td>9.27 ± 3.67a</td>
<td>−43.30 ± 19.52a</td>
<td>0.04 ± 29.40a</td>
</tr>
<tr>
<td></td>
<td>(3.02 to 12.73)</td>
<td>(−66.47 to −19.94)</td>
<td>(−35.69 to 38.22)</td>
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<tr>
<td>Combined muscle bellies</td>
<td>16.36 ± 4.33a</td>
<td>−58.93 ± 20.45a</td>
<td>6.59 ± 30.92a</td>
</tr>
<tr>
<td></td>
<td>(9.55 to 20.05)</td>
<td>(−82.00 to −27.28)</td>
<td>(−20.71 to 49.71)</td>
</tr>
</tbody>
</table>

*a,b Different superscript letters within a column indicate significantly (P ≤ 0.05) different values.*

**Discussion**

In this study, the lateral belly of the equine CAD muscle was found to be more influential in producing arytenoid abduction, as was found in a previous study. The PCSA of the medial and lateral muscle bellies was found to be similar in the present study. Muscle force generation capacity is directly related to PCSA, thus suggesting the force output of the 2 bellies is similar during arytenoid abduction, assuming the same motor unit size and degree of recruitment. Differences were, however, seen in muscle mass, volume, and fiber length between the 2 bellies. The lateral muscle belly had a longer mean fiber length, which enables greater shortening during contraction and may therefore explain the greater range of arytenoid movement observed.
propose that the relatively increased proportion of type I fibers in the lateral belly and its increased rotational action, compared with that of the medial belly, reflects its function in sustained, fatigue-resistant abduction of the arytenoid cartilage during prolonged exercise.

Rocking is a type of rigid body motion described as rotation about a moving axis. The lateral muscle belly was associated with greater pitch of the dorsal arytenoid plane and greater mean caudal displacement at the MPA than the medial muscle belly, thus indicating that the lateral belly contributes more to the rocking motion of arytenoid abduction, which results in rima glottidis dilation. Greater lateral and dorsal arytenoid displacement was reported following electrical stimulation of the lateral muscle belly, compared with the medial muscle belly, in equine larynges. Similar findings have been reported for dogs in which the analogous vertical and oblique bellies of the PCA rock the arytenoid backward while sliding it laterally, causing maximal airway dilation. Furthermore, in humans, the lateral PCA belly's action involves more rocking and less swiveling (external rotation about a rostrocaudal axis, analogous to yaw in this study) than does the medial belly. The medial muscle belly generated more roll of the ventral arytenoid plane. The analogous horizontal muscle belly of the human and canine PCA was found to swivel the arytenoid, supporting these findings.

Arytenoid marker displacement and percentage maximal roll and pitch of dorsal and ventral arytenoid planes increased rapidly at low amounts of forces before leveling out to only gradual changes with higher amounts of force. This characteristic may have been attributable partially to absence of passive reciprocal force from the laryngeal adductor muscles (because in this study they were transected), given that the lateral cricoarytenoid muscles and PCA muscles (analogous to the equine cricoarytenoideus lateralis and CAD muscles) are described as a direct agonist-antagonist pair. The CAJ capsule may also control motion of the arytenoid cartilage, although, given its thin, loose nature, we believe this to be only minor. Likely of greater functional importance in the motion characteristics of the arytenoid at low and high forces was constraint from the cricoarytenoid ligament, which supports the ventromedial aspect of the CAJ capsule, attaching the inner surface of the cricoid lamina (close to the arytenoid articular surface) to the medial surface of the arytenoid cartilage (ventral to the articular surface).

The displacement elicited by both muscle bellies was less than the sum of the medial and lateral bellies, thus indicating slight antagonism between the medial and lateral bellies. Arytenoid cartilage rocking associated principally with the lateral muscle belly results mainly in caudal displacement of the arytenoid articular facet, which tenses the cricoarytenoid ligament and results in a tendency for the arytenoid cartilage to rotate medially into the lumen of the rima glottidis. We therefore propose that the action of the medial muscle belly in creating greater rolling of the ventral arytenoid plane acts to antagonize the action of the ligament by preventing the vocal process of the arytenoid cartilage from narrowing the rima glottidis. The medial part of the corresponding ligament in humans has been shown to act antagonistically to the actions of the PCA muscles. The posterior portion of this ligament in humans has been described as functioning as a stabilizer and pivot point in lateral abduction, whereas the anterior part acts to prevent backward tilting. This stabilizing action is supported by evidence that transection of the cricoarytenoid ligament in humans results in increased CAJ laxity and range of motion.

The marker at DorC remained stationary during arytenoid abduction as the MPA was displaced caudally. We assume this is the result of tension in the ligamentous attachment of the arytenoideus transversus between the right and left arytenoids. This 8% increase in length between the markers resulted in deformation of the cartilage due to the elastic nature of the horn-shaped dorsal aspect of the corniculate process of the arytenoid cartilage. The finding of considerable compliance in the dorsal aspect of the arytenoid cartilage is in contrast to the previous assumptions that the human and equine arytenoid cartilage acts as a rigid body. The corniculate cartilage in humans is also composed of elastic cartilage. We believe the elastic nature of the cartilage and its ability to deform enables maximal dilation of the rima glottidis, so during simultaneous abduction of both arytenoid cartilages, neither right nor left arytenoid cartilages are displaced medially into the lumen of the glottis.

As a consequence of the corniculate process of the arytenoid cartilage not behaving as a rigid body, our calculated rotational data for the dorsal arytenoid plane may not fully reflect the rotational component of the arytenoid cartilage articular facet's rocking on its cricoid counterpart. Despite this, the rotational data for the ventral arytenoid plane remains valid to determine overall arytenoid cartilage motion. The axes used to define these rotations may also have limited complete interpretation, and in the future, it may be preferable to align axes with the longitudinal axis of the cricoid articular facet (with which the arytenoid cartilage appears to rock). This, however, would necessitate crico-arytenoid disarticulation.

This study has generated data that aids elucidation of the complex movements of the CAJ and in particular the action of the CAD muscle and its constituent bellies. Although important from an anatomic perspective, the movement of this joint and the action of the CAD muscle are important clinically in horses with recurrent laryngeal neuropathy because prosthetic laryngoplasty (mimicking the action of the CAD muscle by suture placement) is the accepted surgical treatment of the condition. The current data suggest that suture placement should mimic the action of the lateral muscle belly, rather than the medial muscle belly, because this will maximize the rocking motion of the arytenoid cartilage that causes abduction. However, an additional suture placed along the line of action of the medial muscle belly may prevent medial displacement of the vocal process into the glottic lumen, as the arytenoid abducts, thereby further contributing to rima glottidis dilation. During laryngoplasty, suture placements through the MPA that mimic the insertion of the CAD muscle onto the spine of the arytenoid cartilage have been shown to have an increased force to construct failure.
References