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UPPER RESPIRATORY TRACT FUNCTIONAL DISORDERS IN SPORT AND PLEASURE HORSES

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CONTENTS

ABBREVIATIONS

ACC Arytenoid cartilage collapse

CAL Cricoarytenoideus lateralis

CAD Cricoarytenoideus dorsalis

EE Epiglottic entrapment

ER Epiglottic retroversion

CPH Colombian paso horses

DDSP Dorsal displacement of the soft palate

DLC Dynamic laryngeal collapse

HSTE High speed treadmill endoscopy

LRT Lower respiratory tract

MCME Medial collapse of the margins of the epiglottis

MDAF Medial deviation of the aryepiglottic fold

NPC Nasopharyngeal collapse

OGE Overground endoscopy

PI Palatal instability

PHC Pharyngeal collapse

RDPA Rostral displacement of the palatopharyngeal arch

RLN Recurrent laryngeal neuropathy

RLn Recurrent laryngeal nerve

TL Tracheal lavage

URT Upper respiratory tract

VFC Vocal fold collapse

VLAC Ventromedial luxation of the apex of the corniculate process of the arytenoid

VRDDLM Ventrorostral displacement of the dorsal laryngeal mucosa

4BAD 4^{th} branchial arch defect

1. LITERATURE REVIEW

Poor performance may be related to a number of different origins in horses, including the upper and lower respiratory tract, musculoskeletal problems, cardiovascular disorders, nervous system and gastrointestinal tract diseases. Respiratory problems are the most common cause, after musculoskeletal problems, of poor performance in horses (Martin et al., 2000).

1.1. Physiology of upper respiratory tract

Horses – contrary to human beings – are obligate nasal breathers, they cannot switch from nasal to oro-nasal breathing. They can only decrease the air resistance by contracting the musculature of the upper respiratory tract (URT) (Art et al., 1990).

During inspiration, when the diaphragm contracts, negative pressure develops in the upper and the lower respiratory tract. The nasal passages (26–76%), followed by the larynx (12–30%), produce the greatest resistance to airflow within the upper airway. Airflow volume is substantially increased during exercise, resulting from the increased negative pressure. The nasopharynx and the larynx have a tendency to collapse, since neither of them has a bony/stiff structure, and active muscle work is needed to prevent this (Barakzai, 2007).

Especially relevant to dilation and stability of the upper airway during exercise are the pressure receptors. Negative pressure within the upper airway increases the activity of strap muscles. They are stimulated during upper airway obstruction, when large collapsing pressures are produced in the upper airway, and they provide afferent information to the central nervous system, signaling contraction of upper airway muscles to resist dynamic collapse in the upper airway. Local sensory receptors in the upper airway of horses contribute to upper airway patency and that disrupting the sensory component of the local reflex that controls contraction of upper airway muscles can cause dynamic upper respiratory obstruction in horses. If the respiratory tract is obstructed, vortices causing abnormal respiratory noise may develop (Art et al., 1990; Barakzai, 2007).

Any factors that increase negative pressure in the URT, e.g. poll flexion, increased pressure in the lower respiratory tract or multiple obstructions (Ducharme, 2009), or constitutional changes (Susan J. Holcombe et al., 2010) can markedly influence the mechanics of the URT. When evaluating the URT, we also have to consider possible causes of nasopharyngeal instability, such as an immature nasopharynx or inflammation of the URT/LRT.

1.2. Endoscopic examinations

1.2.1. Resting vs. exercising endoscopy; How to perform examinations

The endoscope is a valuable tool for non-invasive exploration of body systems and cavities. In most cases, the passage of the endoscope through the nasal chambers is not resented by horses (Lane, 1981), although it may be slightly uncomfortable and some form of restraint is needed to insert the endoscope (Kenneth and Kaneps, 2004). Evaluation of nasopharyngeal or laryngeal function cannot possibly be made correctly in a sedated patient since chemical sedation may significantly affect the appearance and movements of these structures (Barakzai, 2007). In a small number of patients, there may be need to use a chemical restraint but artefacts such as asynchronous movements by the arytenoid cartilages and a tendency to rostral displacement of the palatopharyngeal arch may be produced (Barakzai, 2007). A critical evaluation of subtle functional changes will no longer be possible under sedation and therefore diagnostic significance should be attached only to gross malfunctions (Art and Bayly, 2013). A physical restraint such as a twitch is usually sufficient with the horse in stock or even backed into the corner of a box (Barakzai, 2007).

A resting endoscopic examination (Figure 1-2.) is useful in identifying URT structural obstructive conditions and may also give information regarding the nasopharyngeal and laryngeal function (Barakzai and Dixon, 2010). A thorough endoscopic investigation of the URT should examine both nasal passages, guttural pouches and the nasopharynx and the larynx.

Figure 1: Resting endoscopy (Source: own image)

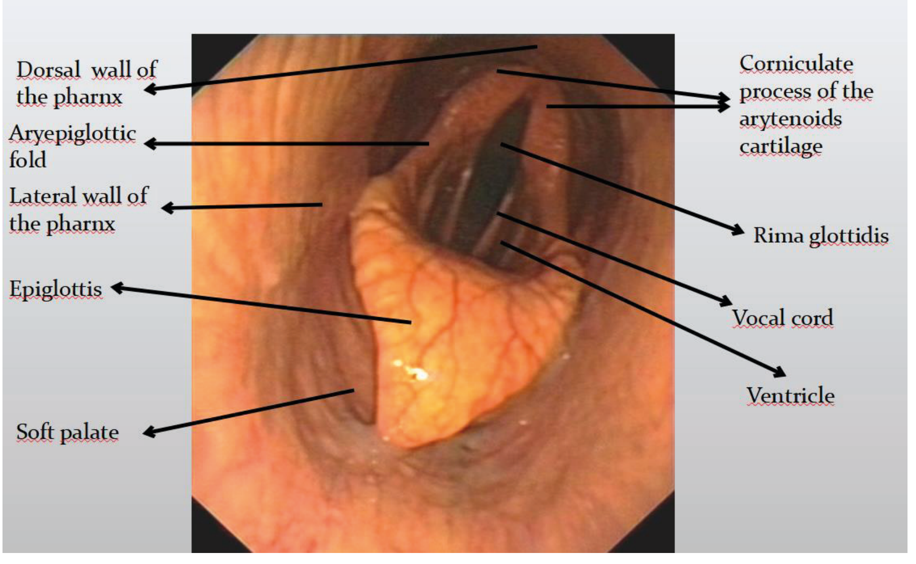

Figure 2: Normal endoscopic anatomy of the pharynx and the larynx (Source: own image)

Nasal occlusion may stimulate the upper airway pressures achieved during high intensity exercise and so can mimic conditions by increasing the negative pressure experienced during exercise. Nostril occlusion during resting endoscopy may be routinely used to assess pharyngeal muscle function and arytenoid function at rest (Art and Bayly, 2013). The induction of swallowing by introducing a small amount of water or a probe may assist to show laryngeal function and intermittent EE may be revealed also upon swallowing. Dorsal displacement of the soft palate may occur spontaneously in response to nostril occlusion or the induction of swallowing (Holcombe et al., 1996).

Another test which is performed at rest and may be used for the investigation of laryngeal function is the “slap test” (thoracolaryngeal reflex). Slapping one hemithorax, typically in the saddle area behind the withers causes a reflex adduction of the muscular process of the arytenoid cartilage on the contralateral side. This reflex may be absent or reduced in animals with lesions of ascending cervical spinal cord tracts, other spinal cord lesions and RLN however, the sensitivity of the slap test was also found to be low (Newton-Clarke et al., 1994).

Some clinicians perform an endoscopic examination immediately after exercise in an attempt to improve the diagnostic value of resting endoscopy. However, most forms of dynamic upper airway obstructions or collapse disappear within seconds of stopping exercise so the benefit of investigating the URT by endoscope at rest even after exercise is lost (Art and Bayly, 2013). Since the emergence of exercising endoscopy in the 1990’s with HSTE and video endoscopy, veterinary surgeons have readily adopted dynamic endoscopic examinations in addition to resting endoscopic examinations (Barakzai, 2007).

Indications for exercising endoscopy include abnormal respiratory noise, poor performance and horses with abnormal findings during endoscopy at rest (Art and Bayly, 2013). Before performing a dynamic endoscopic examination, it is important to inform clients of the possible outcomes from the investigation. If the disorder is intermittent in nature, then it may not be reproduced accurately during the examination. After the endoscope is inserted into the nostril, the positioning of the endoscope should be that both the arytenoid cartilages and the tip of the epiglottis are clearly visible in the same field of view. The external part of the endoscope should then be secured to the horse whilst maintaining as accurately as possible the normal head and neck position during exercise for the horse. After the endoscope is fitted to the horse, the image should be adjusted so it is visible on a remote computer for real time evaluation of the endoscopic examination. An USB may be used to record the endoscopic video for post-examination and it may be useful to watch the video frame-by-frame in order to see subtle changes in the laryngeal and pharyngeal regions (Joó et al., 2014).

1.2.2. High speed treadmill endoscopy vs. overground endoscopy

To establish a definitive diagnosis of URT obstruction, exercising videoendoscopy is regarded as the ‘gold standard’ method (Lane et al., 2010). Until recently, dynamic endoscopy has only been performed on high-speed treadmill endoscopy (HSTE). Different protocols exist in different equine hospitals; however, a similar pattern is followed by each. During HSTE testing the horses must be trained to use the treadmill. The horses are introduced to and schooled on the treadmill at a slow speed to begin with. The testing speeds, distances and inclines are decided upon by the examiner according to the capabilities of the individual horse. They are then fitted with their bridle only or sometimes with both their bridle and saddle. The horses are schooled until they have acclimatized to and are deemed proficient in exercising on the treadmill apparatus. Then the HSTE testing may be performed (Tan et al., 2005).

The advent of another type of dynamic endoscopy now referred to as “overground endoscopy” (OE, Figure 3a-b) has allowed horses to be examined during exercise under normal training conditions and in their normal environment

(Pollock et al., 2009). The pioneering of OE proved very successful since treadmill exercise does not always allow reproduction of the exact conditions of dynamic obstructions of the equine URT (Art and Bayly, 2013). It provides real-time visualization of the URT and recorded video-endoscopy for post-test reviewing. It also provides a safe and effective system for imaging the equine URT during ridden exercise at speed (Pollock et al., 2009).

Figure 3a: Overground endoscopy saddle pad (Optomed). Endoscopy was performed using a 1 m long, 9.8 mm diameter endoscope attached to a specific saddle pad on the horse, designed to carry the processor and the recorder. (Source: MTA - SZIE Large Animal Clinical Research Group)

Figure 3b: Overground endoscopy saddle pad fitted under horse's own saddle (Optomed). The saddle pad was fitted on top of the numnah and under the horse’s own saddle. A specific bridle designed to carry the endoscope was fitted over the horse's own bridle. (Source: MTA - SZIE Large Animal Clinical Research Group)

Both HSTE and OE have their advantages and disadvantages. The criticisms for HSTE and OE appear to stem from the suitability of each method to the horse’s event discipline. For example, one argument against OE is that normal racing conditions may not be appropriately replicated. Strenuous exercise tests may be more easily performed on a treadmill than by performing multiple exercise intervals in the field (Allen and Franklin, 2010). The extent of strenuous exercise that the horse is put under in HSTE is under the control of the veterinarian and not the rider, as most riders tend to pull the horse up when they hear the abnormal respiratory noise. With HSTE the horse can be brought up to maximum exercise, until the abnormality is apparent or the horse shows signs of fatigue (Allen and Franklin, 2010; Art and Bayly, 2013). This benefit of HSTE would be most useful in the examination of the URT of racehorses presenting with poor performance and/or abnormal respiratory noise, since the racing discipline demands that the racehorses compete at maximal speeds, much more so than any non-racing sport horse (Tan et al., 2005).

The arguments against HSTE includes the cost of the equipment, the limited availability of high-speed treadmills, the safety risk to the horses and the handlers and also the time taken to train both the handlers and the horses to be examined and also that HSTE fails to recreate normal exercise conditions with the influence of the rider being present (Art and Bayly, 2013). This is of particular importance in non-racing sport horses, as some of the manoeuvres or movements required of these sport horses could be contributing factors in the development of dynamic airway instability (Van Erck, 2011). Head flexion is a contributing factor to an increase in URT resistance (Petsche et al., 2010), therefore head flexion during ridden exercise could be important in the induction of an abnormal respiratory sound at exercise. Van Erck (2011) concluded that in cases of upper airway dynamic obstruction, rider intervention during ridden exercise can contribute to increasing laryngeal and/or pharyngeal instability in sport horses and therefore OE should be the preferred method for evaluation of the upper airways in sport horses since these changes would not usually be seen with HSTE (Figure 4a-b).

Figure 4a: Overground endoscopy examination in a racehorse (Optomed)

(Source: MTA-SZIE Large Animal Clinical Research Group)

Figure 4b: Overground endoscopy examination in a sport horse (Optomed)
(Source: MTA - SZIE Large Animal Clinical Research Group)

1.3. Common upper respiratory tract functional disorders

Upper respiratory tract functional disorders impede the ventilation and aggravate hypoxemia, which is already induced by exercise in physiologic state. They decrease oxygen consumption and increase the resistance of the airways. Upper respiratory tract functional problems may be dynamic, only appearing during exercise, and static, already visible at rest (Franklin and Allen, 2017). For the evaluation of URT functional disorders endoscopic examinations are performed (described in Chapter 1.2.). In some cases, for better understanding the background of the diseases, additional ultrasonography, radiologic examination or computer tomographic assessment is needed (Kenneth and Kaneps, 2004).

1.3.1. Arytenoid cartilage collapse

1.3.1.1 Recurrent laryngeal neuropathy (RLN)

The RLN is the most common cause of arytenoid and/or vocal fold collapse during exercise (Kenneth and Kaneps, 2004). It has been also termed as idiopathic left laryngeal hemiplegia (ILLHP) in the past or roaring in colloquial language (Barnett et al., 2015). The RLN is a distal axonopathy of the recurrent laryngeal nerve (RLn) with clinical manifestation predominantly (95%) on the left side. Both incomplete adduction and abduction of the arytenoids cartilage result in airway obstruction during inhalation (Art and Bayly, 2013).

The first muscle groups affected appear to be the adductor muscles and within the adductor group the cricoarytenoideus lateralis (CAL) is among the earliest and most severely affected muscles (Ducharme, 2016). Both the cricoarytenoideus dorsalis (CAD) − abductor muscle − and the CAL − adductor muscle − are innervated by the ipsilateral RLn. With idiopathic RLN or with trauma/damage to the RLn, both muscles are subjected to denervation atrophy. The innervation to the CAL is longer than to the CAD and histopathological evidence of denervation is more severe in the CAL than the CAD muscle (Duncan et al., 1991). Therefore, the evaluation of CAL muscle (ie.: laryngeal ultrasonography) should be a good surrogate of the evaluation of the status of the disease (Chalmers et al., 2012). The left RLn, which is 30 cm longer than the right in tall breeds, courses around the aortic arch before innervating the muscles of the larynx. Therefore, it is more predisposed to damage, as it has a very long, tortuous pathway to the larynx (Brakenhoff et al., 2006).

The cause of the disease is largely unknown. Association with horse's height and genetic basis on increased prevalence of the disease have been documented (Ohnesorge et al., 1993). Aside from idiopathic RLN, any trauma or diseases affecting the vagus or the RLn can result in the same condition. Indeed, perivascular injection, esophageal surgery, guttural pouch mycosis, head or neck trauma, abscess formation (strangles) can all result in RLN (Chalmers et al., 2015).

Clinical signs including exercise intolerance and inspiratory noise such as roaring or whistling during exercise indicate this disease. As a first step of the diagnostics, during physical examination it is possible to detect the change in the CAD muscle volume, by digital palpation. This should be followed by a resting endoscopy examination, where abduction and the adduction of the processus corniculate of the arytenoid cartilages are investigated during provocation tests such as nasal occlusion test and thoracholaryngeal reflex (Holcombe et al., 1996). Table 1 describes the Havemeyer grading system, whereby a 4-grade system (I-IV), with the subgrades (I/1,2, III/1,2,3) are appointed according to the severity of laryngeal dysfunction observed during rest (Robinson, 2010).

Table 1: Havemeyer scale of laryngeal function (Robinson, 2010)

Grades	Subgrades
I. All arytenoid cartilage movements are synchronous symmetrical and full arytenoid cartilage abduction can be achieved and maintained.	
II. Arytenoid cartilage movements are asynchronous and/or the larynx is asymmetrical at times but full arytenoid cartilage abduction can be achieved and maintained.	**1.** Transient asynchrony, flutter or delayed movements are seen. **2.** There is asymmetry of the rima glottidis much of the time due to reduced mobility of the affected arytenoid and vocal fold but there are occasions typically after swallowing or nasal occlusion when full symmetrical abduction is achieved and maintained.
III. Arytenoid cartilage movements are asynchronous and/or asymmetric. Full arytenoid cartilage abduction cannot be achieved and maintained.	**1.** There is asymmetry of the rima glottidis much of the time due to reduced mobility of the arytenoid and vocal fold but there are occasions typically after swallowing or nasal occlusion when full symmetrical abduction is achieved but not maintained. **2.** Obvious arytenoid abductor deficit and arytenoid asymmetry. Full abduction is never achieved. **3.** Marked but not total arytenoid abductor deficit and asymmetry with little arytenoid movement. Full abduction is never achieved.
IV. Complete immobility of the arytenoid cartilage and vocal fold.	

Asynchrony of the laryngeal cartilages occurs commonly and with variable clinical relevance at rest. However, horse's that show exercise intolerance or abnormal respiratory noise during exercise or if laryngeal asynchrony is detected during resting endoscopy, should have their laryngeal function evaluated during exercise also. Arytenoid cartilage collapse during exercise can also be classified (Grade A, no collapse; B, partial collapse; and C, collapse) as described in Table 2 (Rakestraw et al., 1991).

Table 2: Grading system of arytenoids cartilage collapse (Rakestraw et al., 1991)

Grade	Interpretation
A	Full abduction of arytenoid cartilages during inspiration
B	Partial abduction of the affected arytenoid cartilages (between full abduction and the resting position)
C	Abduction less than resting position including collapse into the contralateral half of the rima glottidis during inspiration.

Barakzai and Dixon (2010) correlated the resting Havemeyer laryngeal grade with exercising grade in 272 horses. They reported that 4% of grade I laryngeal RLN (full arytenoid function) had arytenoid or vocal fold collapse at exercise. It was also demonstrated that 34% of horses with Grade III RLN had full laryngeal function at exercise. In this study all hores observed with grade IV RLN at rest, showed a complete collapse of the arytenoids during exercising endoscopy (Barakzai and Dixon, 2011).

The treatments for RLN include laryngoplasty (tie-back surgery), ventriculocordectomy and reinnervation. The choice of treatment is laryngoplasty, which is most frequently performed besides ventriculocordectomy. There are no added benefits in terms of airway patency of performing ventriculocordectomy unilaterally or bilaterally after a laryngoplasty has been performed. Laryngoplasty alone reduces abnormal upper respiratory noise, but not as effectively as bilateral ventriculocordectomy (55). Furthermore, it is associated with complications, such as prosthesis failure, chondritis, exercise induced pulmonary hemorrhage (EIPH), esophageal reflux, and dorsal displacement of the soft palate (Ducharme, 2016).

1.3.1.2. Laryngeal collapse without RLN

Dynamic Laryngeal collapse (DLC)

Dynamic Laryngeal collapse (DLC) associated with poll flexion is a dynamic upper airway disorder in horses, characterized by bilateral collapse of the arytenoids cartilages and vocal folds during head and neck flexion. This occurs because poll flexion leads to a more cephalic position of the larynx and narrowing of the laryngeal diameter (Hanche-Olsen et al., 2010). The disorder is relatively newly described in literature and most frequently predisposed in the Scandinavian harness racehorses, namely in the Norwegian Coldblooded trotters and in the Standardbreds (Fjordbakk et al., 2008). But it has also been reported in other breeds like Icelandic horses with Tölting gait (Hanche-Olsen et al., 2010).

Although some histopathological evidence of RLN is present, the prevalence of this histopathological lesion is similar to those of non affected controls (Fjordbakk et al., 2015). These animals do not respond well to ventriculocordectomy with or without laryngoplasty. Rider modification or a device that restricts poll flexion, has been shown to resolve the problem (Fjordbakk et al., 2008).

Laryngeal dysplasia

Laryngeal dysplasia is a developmental disease commonly referred to as 4th branchial arch defect (4-BAD) syndrome. Aplasia or hypoplasia of one or more of structures that develop from the 4th or 6th branchial arch may occur and can cause functional problems. The severity of clinical manifestation ranges broadly and is based on the degree of the defect (Garrett et al., 2009). Diagnosis can be made in most cases using a combination of laryngeal palpation and endoscopic examination at rest. It should be noted that although cases are most commonly right-sided (62%), bilateral (24%) and left-sided (14%) cases have also been reported (Barakzai, 2016). There is no obvious explanation for the right-sided predilection of this disorder. Palpation of the larynx reveals absence of one or both wings of the thyroid cartilage, resulting in failure of the cricothyroid articulation and a palpable space between the cricoid and thyroid cartilages. According to the theory of Barakzai it is possible that the prevalence of right- and left-sided cases is actually more even than these statistics suggest. This is because some cases of left-sided laryngeal dysplasia, which show only reduced arytenoid abduction endoscopically, may easily be misdiagnosed as recurrent laryngeal neuropathy (Barakzai, 2016). Rostral displacement of the palatopharyngeal arch (which is hypothesised to manifest due to absence of upper esophageal sphincter muscles) may or may not be detected during endoscopic examination. Radiography and laryngeal ultrasound can also assist with confirming a diagnosis. Laryngeal ultrasonography is an exceptionally useful tool, since it is possible to identify the absent cricothyroid articulation, consequently it is possible to visualize the CAL muscle bulging out through the abnormal space. Dorsal extension of the thyroid cartilage, above the muscular process of the arytenoid may also be detected in LD (Chalmers et al., 2006). The most common clinical signs of LD are abnormal respiratory noise, coughing (in more severe cases), aerophagia with associated symptoms of eructation and tympanic colic and dysphagia. Horses with LD, which can maintain full or partial arytenoid abduction during exercise, but experience significant airway obstruction due to uni- or bilateral vocal fold collapse, ventriculocordectomy is indicated. In more severe cases with continuous aerophagia, recurrent colic and dysphagia euthanizing the horse can become necessary (Ducharme, 2016).

Ventro-medial luxation of the apex of the corniculate process of the arytenoid (VLAC)

Ventro-medial luxation of the apex of the corniculate process of the arytenoid is an uncommon cause of upper airway dysfunction that may affect the performance of equine athletes. The condition may be unilateral or bilateral, it may be seen only at exercise or already at rest and one cartilage can subluxate ventral to the other or the medial aspect of the apex of left and right cartilages can both be displaced ventrally (Priest et al., 2012). It is suggested that VLAC develops secondary to a structural weakness at the junction of the corniculate and body of the arytenoid cartilage, because of greater percentage of elastic content (Ducharme, 2016). Barakzai et al hypothesized that the condition is due to an abnormally wide transverse arytenoid ligament. Treatment at this time is still experimental (Barakzai et al., 2007).

Arytenoid chondritis

Arytenoid chondritis may lead to different severity of functional problems. It may be uni- or bilateral (Garrett et al., 2013). It develops following mucosal injury to the body of the arytenoid cartilages (Ducharme, 2016). The cause of the mucosal trauma has been associated with direct trauma from endoscopy, nasogastric intubation, inhaled foreign body, or more violent evidence of coughing when both vocal arytenoid processes contact each other. Excessive vocalization has been hypothesized as a cause (Ducharme, 2016). The arytenoid cartilage geometry enlarges, the arytenoid cartilage has progressive reduction in abduction, despite normal neuromuscular laryngeal anatomy. To make a definitive diagnosis, the amorf shape of the arytenoid cartilage can be detected on laryngeal ultrasonography (Chalmers et al., 2006). If conservative therapy (anti-inflammation, antibiotic therapy) is not sufficient, surgical intervention becomes necessary. A partial arytenoidectomy (on performance horses) or subtotal arytenoidectomy (on pasture sound animals) is recommended (Hay et al., 1993). In severe cases permanent tracheostomy may become necessary (Rakestraw, 2014).

Summary of upper respiratory functional problems related to arytenoid cartilage collapses in horses (Joó et al., 2019):

- Recurrent laryngeal neuropathy − RLN
  - During rest:
    - Left side, (rarely on the right side, bilateral) arytenoid functional problem
  - During exercise:
    - Left side, (rarely on the right side, bilateral) arytenoid functional collapse (ACC)
    - Vocal fold collapse – VFC
- Dynamic laryngeal collapse – DLC
  - During rest: no functional problem
  - During exercise:
    - Bilateral ACC
    - Bilateral VFC
- Laryngeal dysplasia – LD, (4th branchial arch defect – 4BAD),
  - During rest
    - Right side (rarely left side, bilateral) arytenoid functional problem

        - Rostral deviation of palatopharyngeal arch – RDPA
    - During exercise:
        - Right side (rarely left side, bilateral) ACC
        - VFC
        - RDPA

1.3.2. Palatal Dysfunction

Palatal dysfunction is most commonly diagnosed in Thoroughbred and Standardbred racehorses but also in horses whose discipline requires them to exercise with their head and neck carried in a flexed position, like dressage horses and Saddlebreds (Franklin et al., 2006). Palatal instability (PI) and DDSP are both syndromes of palatal dysfunction which is one of the most commonly diagnosed causes of upper airways obstruction in horses (Barakzai and Hawkes, 2010). However, it is still unclear if PI and intermittent DDSP are two individual forms of palatal dysfunction, or if they are different severities of the same disorder (Barakzai and Dixon, 2010).

1.3.2.1. Palatal instability (PI)

PI has been described as a wave-like "billowing" of the rostral and caudal soft palate but without actual displacement of the caudal border of the soft palate to the epiglottis (Barakzai and Hawkes, 2010), caudal retraction of the larynx, billowing of the soft palate, flattening of the tip of the epiglottis against the palate with the tip of the epiglottis pointing dorsally and increased frequency of swallowing (Allen and Franklin, 2013). PI may be a precursor to DDSP and may be the only sign of palatal dysfunction in horses not exercised to exhaustion. DDSP may also occur alone, without PI preceding it (Barakzai and Hawkes, 2010).

1.3.2.2. Dorsal displacement of the soft palate (DDSP)

During DDSP, the caudal free margin of the soft palate moves dorsal to the epiglottis, creating a functional obstruction within the airway. The cross-sectional area of the pharynx is reduced and airflow resistance and turbulence are increased. Persistent DDSP is typically identified at rest, whilst intermittent DDSP may be detected at rest or during exercise (Ducharme, 2016). Dorsal displacement of the soft palate has previously been associated with abnormal epiglottic conformation or epiglottic hypoplasia (Barakzai and Hawkes, 2010). However, more recent studies report that the majority of horses with DDSP have in fact a normal epiglottic appearance. In addition, there is both clinical (Parente et al., 2002) and experimental (Holcombe et al., 1999) evidence to support the theory that the epiglottis is not required to maintain the soft palate in a normal subepiglottic position.

Whilst several theories have been proposed, there is little evidence to support a definitive etiology and pathogenesis of palatal dysfunction. As described above, DDSP has various manifestations, the reason for which is still unknown but is most probably as a result of a multi-factorial etiology (Barakzai and Hawkes, 2010).

The treatment of DDSP must be tailored to the cause (Ducharme, 2009) and research has mainly focused on three theories with the main aim being to improve treatment. These theories are neuromuscular dysfunction of the intrinsic soft palate muscles, positioning of the laryngohyoid apparatus (Ducharme, 2009; Woodie et al., 2010) and the role of the distal hypoglossal nerve in maintaining nasopharyngeal stability (Susan J. Holcombe et al., 2010) (Table 3).

Table 3: Etiology of dorsal displacement of the soft palate (Ducharme, 2009)

Extrinsic causes of DDSP	Intrinsic causes of DDSP
Caudal position of the larynx respective to the soft palate and basihyoid bone.	Structural anomalies: e.g. subepiglottic cysts, epiglottic granulomas.
	Neuromuscular weakness: e.g. URT infection

URT = upper respiratory tract

DDSP = displacement of the soft palate DDSP

Horses with structural abnormalities of the larynx and nasopharyngeal region leading to DDSP must have the primary lesions or disorders corrected first. However, when no structural anomaly of the larynx is identified, the cause of the DDSP is more difficult to find (Ducharme, 2009). The lack of knowledge of the pathophysiology of DDSP is a major contributing factor to limited success of most treatments (Ducharme, 2016). Controversial yet frequently used topical nasopharyngeal anti-inflammatory preparations may be applied. In racehorses the choice of surgical intervention is a “laryngeal tie-forward” surgery. In sport horses the results of surgical intervention are less predictable unless an intrinsic cause is found (Ducharme, 2009). Thermocautery of the soft palate is performed to increase rigidity in the soft palate. Despite being widely performed throughout the UK, Barakzai (2015) reported that the success of thermocautery is only modest (28-59%) and suggests further investigation of the technique, specifically the evaluation of mechanical and histological changes in the cauterized palate is warranted (Barakzai, 2015).

1.3.3. Pharyngeal collapse (PHC)

Pharyngeal collapse is a common finding is sport horses. It was found more common in sport horses than in racehorses with neck flexion being cited as an important contributing factor (Boyle et al., 2006). Pharyngeal wall collapse has also been associated with URT inflammation. However, the etiology is unknown in the majority of cases (Kenneth and Kaneps, 2004). Dynamic PHC may involve either the lateral pharyngeal walls or the dorsal wall or a combination of both with an upward movement of the soft palate, causing a pronounced circumferential collapse of the pharynx (Boyle et al., 2006). Horses with PHC make a rough or musical sound upon inspiration during exercise, which may be confused with a laryngeal collapse but most afflicted horses have no notable findings at rest (Franklin and Allen, 2017). When performing an endoscopic examination, it is necessary to position the endoscopy rostrally in order to observe lateral pharyngeal wall collapse. If the upper airways are only observed from the normal endoscope position closer to the larynx, pharyngeal wall collapse may be missed (Franklin, 2008).

Treatment options include systemic and topical anti-inflammatory drugs to help reduce the collapse due to inflammation. Also, modification by the rider of poll flexion in the affected horse may improve the condition. Surgical options for nasopharyngeal obstructions caused by poll flexion include trans-endoscopic laser surgery, whereby trans-endoscopic laser fenestration of the median septum and resection of the salpingopharyngeal fold of the guttural pouch is performed (Barton and Gehlen, 2016).

1.3.4. Other functional disorders

In case of epiglottic entrapment (EE), the aryepiglottic fold completely envelops the apex and lateral margins of the epiglottis. The general shape of the epiglottis is visible, and the position (dorsal to the soft palate) is appropriate.

However, the margins of the epiglottis are obscured by a fold of aryepiglottic mucosa. Clinical signs of EE include inspiratory and expiratory noise during exercise and poor exercise performance. Less common signs include cough, nasal discharge, and headshaking (Ducharme, 2016).

Epiglottic retroversion (ER) is a rare laryngeal disorder. It occurs when the epiglottal apex regresses into the rima glottidis during inspiration, causing an obstruction at the entrance to the trachea and then returns to the normal resting position during expiration (Parente et al., 1998). The result of ER is significantly reduced airflow during inspiration and inspiratory noise. Whilst the etiology of ER is still unknown, ER has been recreated experimentally by anaesthetizing the geniohyoid muscle and the hypoglossal nerves at the level of the guttural pouch. Epiglottic retroversion has also been reported following severe respiratory infections or following surgeries that caused damage to the hypoglossal nerves, supporting the suggestion, that the hypoglossal nerves and subsequent paresis of the geniohyoid muscles are involved in the pathogenesis (Franklin, 2008).

Medial deviation of the aryepiglottic folds (MDAF) is an inspiratory laryngeal disorder that occurs during exercise. The etiology is as yet unknown. However, immaturity and fatigue have been cited as playing a role in the pathogenesis of MDAF (King et al., 2001). During ADAF, the membranous portions of the aryepiglottic folds move in an axial direction, towards the center of the airway lumen resulting in a dynamic URT obstruction. Medial deviation of the aryepiglottic folds may be bilateral or unilateral with the right side being more commonly affected (King et al., 2001). Typical clinical signs include abnormal respiratory noise and exercise intolerance. However, MDAF is more typically a cause of respiratory noise without poor performance according to another study (Ducharme, 2016). It is a true dynamic disorder of the URT and only occurs during strenuous exercise (King et al., 2001). For this reason, high-speed treadmill endoscopy (HSTE), where speed and exercise intensity can be controlled by the veterinarian, is widely accepted as the gold standard for the diagnosis of this disorder (Lane et al., 2010). However, there are recent studies showing MDAF can be successfully diagnosed during OE (Kumaş and Maden, 2013). The key issue is that the horses are strenuously exercised and fatigued with less importance on the movements of the horse and head position. Medial deviation of the aryepiglottic folds may be identified as the sole cause of a URT obstruction, or it may occur with multiple other disorders (Lane et al., 2010).

A newly described condition, ventro-rostral displacement of the dorsal laryngeal mucosa (VRDDLM), has been reported to uncommonly occur with other upper airway abnormalities (Pollock et al., 2013). In this report researchers examined the URT of 600 horses by OE and identified VRDDLM in 12 of the horses. Eight of these horses also had concurrent abnormalities, including vocal fold collapse, ADAF and intermittent DDSP. According to this report, the exact etiology of VRDDLM is as yet unknown, although they do propose that general airway inflammation or airway instability may predispose the horse to this condition.

1.4. Lower and Upper Respiratory Tract is One Unit

It is important to treat the URT and the lower respiratory tract as a unit. The one airway, one disease concept has been advocated in human medicine (Giovannini-Chami et al., 2018; Grossman, 1997). Furthermore, it has also been investigated in equine medicine, whether the relationship between upper and lower airways described in humans could be applied to horses (Koblinger et al., 2011).

In a study from 2011, it has been proposed that upper and lower airways are independent in terms of severity of inflammation (Koblinger et al., 2011). In another paper, it has been observed that pharyngeal inflammation is not associated with changes in the tracheal cytology (Holcombe et al., 2010b) or in the bronchoalveolar lavage (BAL) cytology (Holcombe et al., 2010a). However, several studies establish other possible associations between the upper and the lower respiratory tract. Regarding the relation of upper airway obstruction − recurrent laryngeal neuropathy (RLN) − and exercise-induced pulmonary hemorrhage, it has been proposed that horses with more severe upper airway obstruction may need less strenuous exercise for the development of exercise-induced pulmonary hemorrhage (Cook, 2014; Cook WR, Williams R, Kirker-Head C., 1988). It had also been demonstrated in another study that an upper airway obstruction in exercising horses causes an increase in transmural pulmonary capillary pressure gradient. This may result in the loss of capillary integrity and lead to the rupture of the pulmonary capillaries and consecutive epistaxis (Ducharme et al., 2010). Exercise-induced pulmonary hemorrhage is a common disorder of racehorses (Manohar, 1994), but it is not an exclusive characteristic of Thoroughbreds and Standardbreds, since it may also appear in horses performing less strenuous exercise. A further example for the interplay between the upper and lower airway disorders had been demonstrated in sport horses, where it was concluded that the palatal instability or nasopharyngeal collapse were significantly affected not just by the presence of the upper (pharyngeal), but the lower airway inflammation as well (Van Erck, 2011).

2. CONCLUSIONS BASED ON THE LITERATURE

Upper respiratory tract (URT) functional problems are common disorders among equine athletes and are often associated with poor performance and abnormal respiratory noise during exercise (Morris and Seeherman, 1990). Recently it has been described that the position of the neck can markedly impact the function and the mechanics of the URT in equestrian disciplines (Van Erck, 2011; Wijnberg et al., 2010). In a study, poll flexion during exercise was found to cause a significant increase in the mean peak inspiratory tracheal pressures. Poll flexion may therefore result in upper airway collapse in presumably normal horses and more significantly in horses with already weakened or fatigued neuromuscular function of the URT (Strand et al., 2009). Endoscopy of the upper airways during rest is used to reveal anatomic abnormalities. It may also predict some functional problems and provide information for understanding the causes of some functional diseases. Up to date the gold standard method to establish a definitive diagnosis of URT functional problems is exercising videoendoscopy (Barakzai and Dixon, 2010). The advent of overground endoscopy (OGE) has enabled the monitoring of upper airway behavior in normal exercising conditions and the investment of rider intervention on the laryngeal and pharyngeal stability and function and allow the visual evaluation of URT function with duplication of head/neck position for the particular equestrian activity (Van Erck, 2011). Identifying the definite cause of each URT functional problem, respectively may be challenging, but since treatment must be tailored to the cause, it is fundamental to find an objective way for defining the etiology. Treatment of the URT and the lower respiratory tract as one unit is outstanding, since lower respiratory tract disorders can be frequently accompanied by URT functional disease, on the other hand URT obstructions can be the underlying cause of lower respiratory tract problems (Joó et al., 2014).

Reports of dynamic airway obstructions are primarily concerned with racehorse populations, while reports on such obstructions in other equine disciplines are scarce (Van Erck, 2011).

3. THE OBJECTIVES OF THE THESIS

1. Describing the results of URT diagnostic evaluation with OGE in non-racing sport horses and pleasure horses. (Study 1)

2. Investigate our hypothesis that asthmatic diseases might be an underlying cause of dorsal displacement of the soft palate in horses. We also aimed to investigate the clinical manifestation of DDSP correlated to equine asthma syndrome. (Study 2)

3. Evaluate the upper airway mechanics during OGE examination in Colombian Criollo horses showing abnormal respiratory sound and poor performance during exercise. Furthermore, our goal was to investigate the hypothesis that the characteristics of the special walking gait and the intensively poll flexed neck may play an important role in the mechanics and the function of the URT of the Criollo horses. (Study 3)

4. METHODOLOGICAL SUMMARY OF THE THESIS

The present dissertation is based on three studies. The first and second study was carried out in Hungary (MTA-SZIE Large Animal Clinical Research Group) and the third study was performed at Universidad CES, Medellin, Colombia. After introducing the main characteristics of the upper airway obstructions in non-racing sport horses and pleasure horses in Study 1, we have focused our attention to describe manifestation of particular diseases in detail. A newly described etiology of dorsal displacement of the soft palate was introduced in Study 2, and among others a special manifestation of arytenoids cartilage collapse was investigated in the so-called Colombian Criollo Paso horses in Study 3. Dynamic upper airway problems of this breed have never been investigated in literature before.

4.1. General examinations

The studies were restricted to sport show and pleasure horses referred for respiratory examination with a history of poor performance and/or abnormal respiratory noise.

In Study 1 altogether 19 horses – 9 males, 10 mares – were examined, ranging in age from 4 to 21 years (10.6 ± 4.7). In study 2, 57 horses – 32 males, 25 mares – were examined, ranging in age from 4 to 21 (11.3 ± 3.2) years. In study 3 a total of 40 Colombian Paso horses (CPH) – 16 males, 24 mares – were examined, ranging from 2 to 11,5 years (median 4 or mean 3,48 years) of age. Among the CPHs all lineages – Colombian Paso Fino /n = 8/, Colombian Trocha /n = 21/, Colombian Trocha-gallop /n= 6/, and Colombian Trot-gallop /n = 5/) – were presented.

After recording the medical history and performing a physical examination, horses underwent a resting and overground endoscopy performed with Dynamic Respiratory Scope saddle pad version (Optomed, DR v3, France, Les Ulis) or Tele-View Dynamic Equine Exercise Endoscope (TV-506 Articulating Model,

Figure 5). The scope was passed from one of the nostrils; in order to handle the horse a nose twitch was applied and no sedatives were used. Resting endoscopic examinations were done immediately prior to the exercising tests. The morphology and function of the larynx and pharynx were evaluated, and occlusion test was performed to induce URT obstruction.

OGE was done in an outdoor arena. The horses were ridden by their usual riders, who were instructed to exercise the horses as usual during OGE, according to the level and discipline of the horses. The riders were asked to ride the horses with loose reins and also in poll flexion at each gate. Horses were ridden until fatigue or until it became evident which URT functional disease was causing the poor performance or abnormal respiratory sound.

Figure 5: Fitting overground endoscopy on a Criollo horse (Tele-View)
(Source: own image)

When the history, the physical examination and the clinical signs revealed a significant LRT obstruction, bronchoalveolar lavage (BAL) was performed. Bronchoalveolar lavage fluid cytology values of >10% neutrophils, >5% mast cells, and >5% eosinophils were considered as mild/moderate equine asthma, while the cut off value of severe equine asthma were >25% neutrophils. The importance of BAL fluid cytology was established in light of the history, clinical examination, and endoscopic findings in each case (Couëtil et al., 2016). When inflammation with infectious origin was suspected, culturing of the tracheal lavage (TL) was performed.

Based upon the history and clinical signs of the horses, the tracheobronchial mucus score, the BAL cytology we have divided the horses into groups of mild/moderate or severe equine asthma. All horses with positive culturing of TL were excluded from the study.

4.2. Additional examinations and information

4.2.1. Plasma lactate level

In the study 1 blood samples were collected in order to measure plasma lactate levels. Blood samples were taken from the jugular vein, at the times indicated in Table 4, into vacuum collecting tubes containing sodium fluoride. All samples were carried to the laboratory in a 4 ºC cooling bag within 4 hours after sampling, where the tubes were immediately centrifuged (10 min, 4000 *g*). After separation, plasma lactate levels were analyzed (Olympus AU /640, Japan, Tokyo).

Table 4: Times of blood sample collections

Blood samples	Timing
0	At rest in the box, prior to the exercise
1	During exercise, after the warm-up session,
2	During exercise, after the most intensive workload
3	At rest in the box, 1 h after work

4.2.2. Classification of the horses

In Study 2, based upon the history and clinical signs of the horses, the tracheobronchial mucus score, the BAL cytology we have divided the horses into groups of mild/moderate or severe equine asthma. Additionally, (in 48 cases) TL cytology was also performed, since it has been described in a newly reported study that it may be more specific and more sensitive compared to BAL fluid cytology (Rossi et al., 2018). A neutrophil cut-off value of 20% was used to detect airway inflammation; eosinophils, and mast cells of TL cytology were not taken into account during the diagnostics of equine asthma syndrome.

We have also taken into account whether the horses developed DDSP during resting endoscopy examinations. Based on these considerations the following groups were established (Table 5).

Table 5: The groups of the horses in Study 2

Groups	Disorders
Group 1	Severe equine asthma
Group 2	Severe equine asthma and DDSP
Group 3	Mild and moderate equine asthma
Group 4	Mild and moderate equine asthma and DDSP

DDSP = Dorsal Displacement of the soft palate

4.2.3. Atropine test

In Study 2, besides the clinical examinations described earlier, additionally an atropine test was performed. After administration 0.02 mg/kg bwt atropine intravenously, we performed a second OGE and evaluated if any significant change was present. This examination aimed to evaluate the upper respiratory tract after decreasing lower airway obstruction, which in turn decreased the negative pressure.

4.2.4. Colombian Criollo Paso horses

In study 3, a special breed, the Colombian paso horses (CPH), also called Colombian Criollo Paso horses were investigated. These horses are found throughout most of Colombia. They have been intensively selected for their gaits since the 1980s. The CPH has been divided into four lineages based on their natural gait (Colombian Paso Fino, Colombian Trocha, Colombian Trocha-gallop, and Colombian Trot-gallop). All horses registered in the studbook, Federación Colombiana de Asociaciones Equinas–Fedequinas, are allowed to participate in competitions in Colombia. For each competition, the horses are separated by horse group, sex and age (three categories: 33–42 months, 42–60 months, and more than 60 months), and evaluated by three judges (www.fedequinas.org, Nicodemus et al., 2003; Novoa-Bravo et al., 2018).

All CPHs perform a so-called walking gait, with at least one limb in stance phase (no aerial phase) with high stride frequency, moreover an important feature of the CPH gait is the extensive collection and the high poll flexion of the neck (Nicodemus et al., 2003). This makes the gait even more exhausting to perform and may also be an important factor in the mechanics of the upper airways.

The paso fino gait is performed exclusively by the Colombian Paso Fino group. It is a four-beat, lateral sequence and laterally coupled gait, which has an isochronal beat pattern, and an independent limb movement (Nicodemus et al., 2003). The trocha gait is performed only by the Colombian Trocha and Colombian Trocha-gallop groups. It is a four-beat, lateral sequence and diagonally coupled gait, in which the fore limb hits the ground before the contralateral hind limb, and it has a non-isochronal beat pattern. Often, two limbs are in the stance phase simultaneously (Nicodemus et al., 2003). The trot gait consists of a two-beat isochronal and diagonally coupled gait. It can be considered a variant of the regular trot and is performed by the Columbian Trot-gallop group. The regular trot has an aerial phase, which is the main difference compared with the Colombian Trot where either two or four limbs are in stance phase. Furthermore the Colombian Trocha-gallop and the Colombian Trot-gallop horses also compete in gallop, which is a variant of the traditional canter. This asymmetric gait is a highly collected canter and it has a non-isochronal beat pattern, with at least one limb, always, in stance phase, which is its main distinguishing feature from regular canter (Novoa-Bravo et al., 2018).

4.3· Statistical analysis

Fisher's exact test was used to search for the likeliness of the coincidence of URT–LRT obstructions. Sample averages of the lactate level intervals were calculated with a one-sample *t*-test at 0.95 confidence levels. Paired sample *t*-test was used to compare the averages (Study 1).

Binomial tests (Clopper-Pearson method) with $P \leq 0.05$ significance were used to establish estimated intervals of the measured frequencies of DDSP occurring in the studied groups (Study 2).

A database was created using Microsoft Excel, and statistical analyses and graphs were performed using the SciPy (1.4.1) library of the Python programming language. Frequency of coexistence of different dynamic URT disorders was investigated. For analysis of qualitative variables, frequency tables were evaluated with proportions for each one of the groups (in accordance with the disorders detected). The odds ratio was used as a measure of the association level with a confidence interval of 95%. For all statistical tests a $P \leq 0.05$ was used to determine statistical significance. One-tailed Fisher exact tests were used to check for positive contingency between each pair of functional disorders (Study 3).

5.1. CHAPTER

Evaluation of overground endoscopy findings in sport and pleasure horses

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Original Research

Evaluation of Overground Endoscopy Findings in Sport and Pleasure Horses

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A B S T R A C T

Any factors that increase negative pressure in the upper respiratory tract (URT) can influence its mechanics. The aim of this report was to describe the results of URT diagnostic evaluation with overground endoscopy in sport and pleasure horses. The URT and plasma lactate levels were evaluated during rest and during overground endoscopic examination in 19 cases. Horses performed their normal training session. When history and clinical examination suggested a lower airway obstruction, we performed bronchoalveolar lavage. Dorsal displacement of the soft palate (DDSP) was diagnosed in 8 of 19 horses, which might have developed secondary to URT or lower respiratory tract inflammation or obstruction. DDSP was also detected at rest in four cases. Laryngeal hemiplegia (LHP) was diagnosed in 15 of 19 horses, 11 of which were complex cases with other types of URT obstructions. Severe pharyngeal collapse (PHC), suspected already at rest, was visible in two cases during exercise. In contrast, PHC diagnosed with nasal occlusion at rest in two cases was fully compensated under the rider. Plasma lactate levels significantly decreased during exercise. All DDSP cases were suspected to be of inflammatory or obstructive origin, which is different from findings in racehorses, where extrinsic causes are more common. Resting endoscopic examinations were sensitive in cases of obstructive origin. LHP and PHC could not be predicted on the basis of findings at rest, and increased neuromuscular activity during exercise could compensate for the problem in less severe cases. Decreased levels of lactate could be explained by the increased clearance during exercise.

1. Introduction

Dynamic upper respiratory tract (URT) obstruction is a common cause of abnormal airway noise and exercise intolerance in equine athletes. Several previous studies have documented that these disorders are underestimated or cannot be diagnosed during a resting endoscopic examination. To establish a definitive diagnosis of URT obstruction, exercising videoendoscopy is regarded as the "gold standard" method [1]. In the past 25 years, high-speed treadmill endoscopy made it possible to evaluate the dynamic collapse of the URT [2]. More recently, the advent of overground endoscopy (OE) has allowed the monitoring of upper airway behavior in normal exercising conditions, during ridden or driven exercise in the field [3].

Horses—contrary to human beings—are obligate nasal breathers. They can only decrease the air resistance by contracting the musculature of the URT [4].

During inspiration, when the diaphragm contracts, negative pressure develops in the URT and the lower respiratory tract (LRT). Airflow volume is substantially increased during exercise, which results in increased negative pressure. The nasopharynx and the larynx have a tendency to collapse, because neither of them has a bony and/or stiff structure, and active muscle work is needed to prevent

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this [5]. If the respiratory tract is obstructed, vortices causing abnormal respiratory noise may develop [6].

Any factors that increase negative pressure in the URT, for example poll flexion, increased pressure in the LRT or multiple obstructions [7], or constitutional changes [8], can markedly influence the mechanics of the URT. When evaluating the URT, we also have to consider possible causes of nasopharyngeal instability, such as an immature nasopharynx or inflammation of the URT and/or LRT. Although it is true that dynamic functional disease of the URT can be diagnosed via exercising endoscopy, resting endoscopy can predict certain diseases, provide information for understanding the causes of some functional changes, and it plays an important role in the detection of structural and/or morphologic deformations.

Reports of dynamic airway obstructions are primarily concerned with racehorse populations, whereas reports on such obstructions in sport horses are scarce [9].

Van Erck-Westergren [10] evaluated the effect of head flexion, riding, and airway inflammation in sport horses. For further investigation of this topic, the present report documents 19 cases of dynamic URT obstructions using OE. The aim of this report was to describe the results of URT diagnostic evaluation with OE in sport and pleasure horses.

2. Material and Methods

The study was restricted to sport (national level) and pleasure horses referred for OE with a history of poor performance and/or abnormal respiratory noise. Nineteen horses—16 warmbloods and three ponies—were examined, ranging in age from four to 21 years (10.6 ± 4.7). Seven horses were pleasure horses, five were competing in dressage, and seven were show jumpers. After recording the medical history and performing a physical examination, all horses underwent a resting and OE performed with dynamic respiratory scope (Optomed, DR v3, Les Ulis, France) saddle pad version. The scope was passed from one of the nostrils; to handle the horse, a nose twitch was applied, and no sedatives were used.

Resting endoscopic examinations were done immediately before the exercising tests. The morphology and function of the larynx and pharynx were evaluated, and occlusion test was performed to induce URT obstruction.

Overground endoscopy was done in an outdoor court. The horses were ridden by their usual riders, who were instructed to exercise the horses as usual during OE, according to the level and discipline of the horses. The riders were asked to ride the horses with loose reins and also in poll flexion at each gate. Horses were ridden until fatigue or until it became evident which URT functional disease was causing the poor performance or abnormal respiratory sound. The time when the functional change became most evident was documented, and it was determined whether it was constantly present. During the evaluation of the URT, the following data were documented (Table 1).

When the history, the physical examination, and the clinical signs revealed a significant LRT obstruction, bronchoalveolar lavage (BAL) was performed. When inflammation with infectious origin was suspected, culturing of the tracheal lavage was performed. Tracheal sampling can both reflect the URT and the LRT disorders. When bacteriology samples from the tracheal lavage were positive and there were also endoscopic signs of URT inflammation (lymphoid hyperplasia, red mucosal membranes, and increased amount of mucus in the nasopharynx) and no signs of LRT infection appeared (no alteration on endoscopy of the trachea and main bronchi), then URT inflammation was suspected. For a definitive elimination of the involvement of LRT, BAL cytology should have been performed in these cases. It is the weakness of this report that results are based on findings in clinical cases, where only necessary diagnostic methods could have been performed because of the owner's financial constraints.

Fisher exact test was used to search for the likeliness of the coincidence of URT–LRT obstructions.

Four blood samples were collected to measure plasma lactate levels. 0: blood sample at rest in the box, before the exercise; 1: blood sample during exercise, after the warm-up session; 2: blood sample during exercise, after the most

Table 1
Disorders during resting and overground endoscopy.

Disorders	Resting Endoscopy	Overground Endoscopy
Morphologic changes	Yes/no	—
Lymphoid hyperplasia	I–IV	—
Nasopharyngeal mucus	−, +, ++,	−, +, ++,
PI	−, +, ++,	−, +, ++,
Pharyngeal collapse	−, +, ++, lateral/dorsal/circumferential	−, +, ++, lateral/dorsal/circumferential
DDSP	Yes/no	Yes/no
LHP	I, II/1, II/2, III/1, III/2, III/3, IV (Havemeyer grading system)[a]	—
ACC	—	A, B, C[a]
VCC	—	A, B, C
RDPA	—	Yes/no
ADAF	—	Yes/no
When was the FD the most relevant?	■ Occlusion test ■ Constantly appearing ■ No FD	■ Low/high intensity work ■ Loose reins ■ Poll flexion and low intensity work ■ Poll flexion and high intensity work ■ At fatigue ■ Constantly appearing

Abbreviations: ACC, arytenoid cartilage collapse; ADAF, axial deviation of the aryepiglottic fold; DDSP, dorsal displacement of the soft palate; FD, functional disease; LHP, laryngeal hemiplegia; PI, palatal instability; RDPA, rostral displacement of the palatopharyngeal arch; VCC, vocal cord collapse.
[a] [11].

intensive workload; and 3: blood sample in stall rest (approximately 1 hour) after work.

Blood samples were taken from the jugular vein into vacuum collecting tubes containing sodium fluoride. All samples were carried to the laboratory in a 4°C cooling bag within 4 hours after sampling, where the tubes were immediately centrifuged (10 minutes, 4,000*g*). After separation, plasma lactate levels were analyzed (Olympus AU/640, Japan, Tokyo).

Sample averages of the lactate level intervals were calculated with a one-sample *t* test at 0.95 confidence levels. Paired sample *t* test was used to compare the averages.

3. Results

This is a retrospective evaluation of the findings from the dynamic endoscopic examinations of 19 sport and pleasure horses. The majority (15 of 19) had left laryngeal hemiplegia (LHP) with or without the presence of one or more other abnormalities. Dorsal displacement of the soft palate (DDSP) was the second most common finding. As a first classification of URT functional disease, it was determined whether simple or multiple obstructions were visible during OE. Cases in which arytenoid cartilage collapse (ACC) and vocal cord collapse (VCC) occurred simultaneously or palatal instability (PI) appeared before DDSP were considered as simple cases. All other combinations of URT obstructions were regarded as complex cases.

Considering the whole endoscopic examination (resting endoscopy and OE), 7 of 19 simple and 12 of 19 complex cases were observed. Eight of 19 horses had DDSP, including two simple and six complex cases. One of eight developed DDSP only at rest, whereas among the seven cases where DDSP appeared during exercise, DDSP could be detected at rest in four cases. All the horses were coughing simultaneously with the displacement (>70%, binomial test with $P = .05$) and all but one performed poorly. Abnormal respiratory sounds were detected only in the complex cases and were secondary to URT functional diseases other than DDSP. Regarding the origin of DDSP, in two cases, it might have developed secondary to neuromuscular weakness caused by a suspected URT inflammation and six were most likely due to LRT obstruction, where inflammatory airway disease (IAD) or recurrent airway obstruction (RAO) was confirmed on the basis of BAL cytology. Other reasons such as constitutional problems or immature nasopharynx are unlikely to be predisposing factors of DDSP in our cases, as it is described later in the text.

Severe (++) PI was detected in nine cases; we observed that LRT obstruction and PI typically occurred simultaneously (Table 2) in our population, and their dependence was verified by Fisher exact test ($P = .001$).

Fifteen of 19 cases showed some degree of left LHP, 4 of 15 were simple, 11 of 15 were complex cases where pharyngeal collapse (PHC), DDSP, PI, or rostral displacement of the palatopharyngeal arch occurred besides LHP (Fig. 1). All horses with grade III/2 or IV LHP (seven horses) emitted abnormal inspiratory sounds during training; four

Table 2
Relationship of LRT obstruction and palatal instability.

LRT Obstruction	PI Was Observed (n)	PI Was Not Observed (n)
LRT obstruction	8	1
No LRT obstruction	1	9

Abbreviations: LRT, lower respiratory tract; PI, palatal instability.

of these horses showed poor performance according to their owners. In lower grades (II/1, II/2), abnormal respiratory noise and poor performance appeared secondary to other URT and/or LRT obstructions. Of the nine horses with grade II or III LHP, three were classified as grade A during exercise and six animals developed ACC and VCC when ridden. In one case, where full abduction was visible at rest, grade B, bilateral ACC and VCC were observed during poll flexion. In five cases, grade 4 LHP was detected at rest; besides grade C ACC at exercise, we documented grade C VCC in all cases which were either unilateral, bilateral, ipsilateral, or contralateral. All cases with LHP were idiopathic except one, where distal axonopathy developed secondary to a paravenous injection administered to the left jugular area. In two cases, besides LHP, exercise-induced pulmonary hemorrhage (EIPH) was proven by the presence of hemosiderophages on BAL fluid cytology. In one of the cases, IAD was also confirmed simultaneously with EIPH.

Interestingly, besides PI, grade B ACC and VCC occurred in two ponies. These ponies were performing poorly and had LRT obstructions (IAD).

In six cases, PHC was detected. During exercise, severe PHC was visible in two cases, which could be suspected already at rest. In contrast, in two cases of PHC diagnosed with nasal occlusion at rest, the problem was fully compensated through neuromuscular activity when ridden. In the remaining two cases, mild PHC was only visible during exercise and could not be induced by occlusion test at rest. Abnormal respiratory sounds were obvious in all the severe cases and in one of the mild cases. PHC typically exacerbated during poll flexion (Fig. 2). The

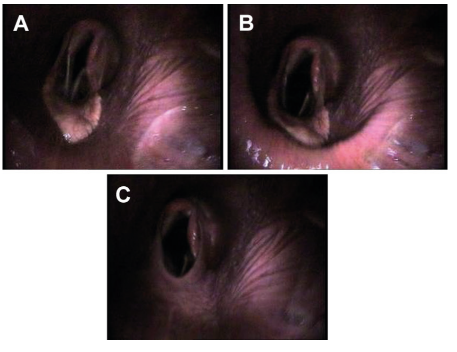

Fig. 1. Complex case. Overground endoscopy image from case 1, showing arytenoid cartilage collapse, vocal cord collapse, flat epiglottis (A), palatal instability before dorsal displacement of the soft palate (B), and dorsal displacement of the soft plate (C).

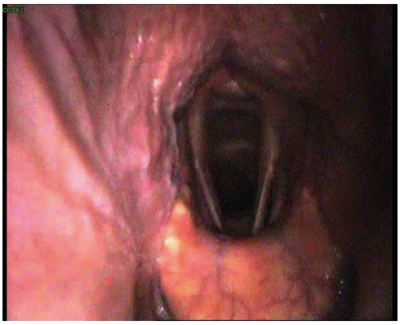

Fig. 2. Dorsal pharyngeal collapse. Upper airway endoscopy of case 16 during poll flexion, dynamic collapse of the dorsal pharyngeal wall is visible.

soft palate was more instable when the rider gathered the horse. The degree of bilateral ACC severely increased during poll flexion in one case (Fig. 3).

The complexity of the cases is illustrated in Figs. 4 and 5.

Sample averages of the lactate levels are presented in Table 3 (intervals calculated with a one-sample *t* test at 0.95 confidence levels). Using a paired sample *t* test, it was confirmed that the values measured during rest (0) are significantly higher than those measured during exercise (1 and 2). The application of this method was justified by the high correlation coefficients ($\sim$0.8 in both cases). When calculated at 0.95 confidence level, the difference between the values at 0 and 1 were 0.44 ± 0.16 mmol/L and between the values at 0 and 3 were 0.32 ± 0.16 mmol/L.

4. Discussion

As it has been described in previous studies, DDSP can be attributed to different causes, and its treatment has to be adjusted accordingly [12]. In the literature, these causes are often divided into two groups depending on whether they are related to the intrinsic muscles (palatinus and palatopharyngeus muscles) [13] or to the extrinsic palatal musculature (thyrohyoid muscle) [9]. Intrinsic causes may involve neuromuscular weakness (e.g., URT infection) or structural deformations (subepiglottic cysts, granuloma, epiglottitis, epiglottic chondritis, and so forth) in the pharynx [13,14]. DDSP that is suspected to develop secondary to neuromuscular weakness because of URT infections should be treated conservatively, with local or

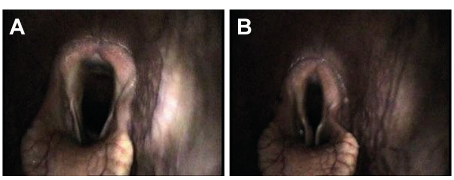

Fig. 3. Bilateral dynamic laryngeal collapse. Endoscopy image obtained from case 12 showing full abduction of the arytenoid while the horse is ridden with extended neck (A) and poll flexion induced, bilateral arytenoid cartilage collapse, and unilateral axial deviation of the aryepiglottic fold (B).

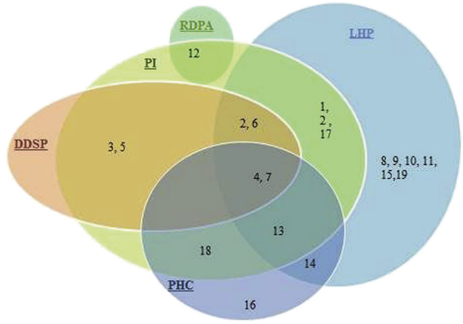

Fig. 4. Results of resting endoscopic examination. The numbers are reflecting the cases. DDSP, dorsal displacement of the soft palate; LHP, laryngeal hemiplegia; PI, palatal instability; PHC, pharyngeal collapse; RDPA, rostral displacement of the palatopharyngeal arch.

systemic anti-inflammatory and antibiotic therapy. These cases are more prone to DDSP subsequent to the more negative pressures of increased respiratory effort because of the neuromuscular weakness. Structural deformations usually need surgical intervention [12]. DDSP is an URT obstruction typical for Thoroughbreds, which usually occurs during high-intensity exercise. In this case, the extrinsic cause is thought to be the relative position of the larynx, excessively caudal, and ventral to the basihyoid and the soft palate [15]. The reason why it is so common in racehorses might be that at high galloping speed, there is a higher chance of development of DDSP, due to the increased activity of the muscles that affect the interrelationships between the larynx, the pharynx, and the hyoid apparatus [16]. In such cases of extrinsic origin, tie forward surgery is the suggested choice of treatment [17]. The success rate of this surgery is 68% to 90%, so there is a nonnegligible chance of failure in general [12]. However, in racehorses, another explanation of unsuccessful tie forward surgery could be that the immature nasopharynx of a

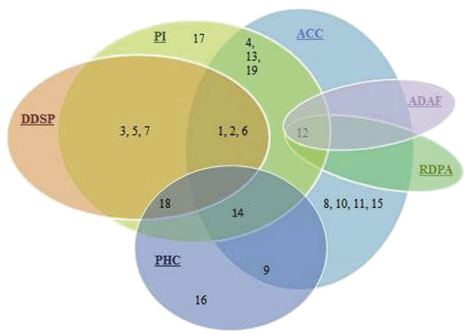

Fig. 5. Results of dynamic URT obstructions during overground endoscopy. The numbers are reflecting the cases. ACC, arytenoid cartilage collapse; ADAF, axial deviation of the aryepiglottic fold; DDSP, dorsal displacement of the soft palate; PI, palatal instability; PHC, pharyngeal collapse; RDPA, rostral displacement of the palatopharyngeal arch; URT, upper respiratory tract.

Table 3
Plasma lactate levels.

Rest/Exercise	Lactate levels
0. Rest (before exercise)	0.93 ± 0.21 mmol/L
1. Exercise (after warm-up session)	0.48 ± 0.08 mmol/L
2. Exercise (after intensive workload)	0.54 ± 0.19 mmol/L
3. Rest (after exercise)	0.75 ± 0.2 mmol/L

young Thoroughbred, which is an intrinsic cause, can lead to the appearance of DDSP, which can be resolved by resting the horse until the nasopharynx matures. This solution might not be feasible for many gallop horses, since the period while they can compete at top level is quite short. This raises the issue whether the immature nasopharynx might be stabilized by sclerotherapy [18] of the soft palate with a diode laser rather than by a tie forward surgery. Immature nasopharynx is not a substantive problem in our population of sport and pleasure horses because of the older age of our cases compared with racehorses.

Negative pressure and inspiratory airflow increase in all cases of exercise, even with the low-to-moderate levels involved in this report. What varies from case to case, with respect to DDSP, is the magnitude of the increase that is required to induce the displacement in a given horse. We propose that DDSP caused by severe LRT obstruction (RAO) is common among the sport and pleasure horses examined in the present study. In these cases, the markedly increasing negative pressure driven by the LRT obstruction might lead to a simultaneous negative pressure increase in the URT resulting in a DDSP. Implicitly, we suggest a primary treatment of the lower airways in these cases. In one case, a less severe URT obstruction (IAD) was suspected to cause palatal dysfunction. In this case, DDSP occurred only at resting endoscopy, during exercise there was only PI visible. The pathomechanism of this might be explained by the following. A good indication of how sympathetic and/or adrenergic drive can overcome the effects of LRT obstruction at rest is that horses with acute LRT obstruction could still exercise as well without treatment as with treatment, due to their own ability to dilate airways [19].

This common cause of DDSP in sport and pleasure horses is unlikely to be the etiology of DDSP in racehorses because race performance could not be performed with such severe LRT obstruction. The most typical cause of DDSP—the ventrally and caudally positioned larynx—in gallop horses is not eliminated in sport horses. However, even if there is a configuration problem such as this in a sport horse, it is unlikely to cause DDSP in the absence of high strap muscle activity. We propose that poll flexion would rather impede the manifestation of DDSP of extrinsic cause in sport horses, whereas the extended neck and the high speed predispose to it in gallop horses.

Concerning the correlation of resting and exercising endoscopic examinations, it is reasonable to sort the cases by the suspected causes. We suggest that this correlation is the highest in DDSP cases caused by LRT inflammation and/or obstruction.

Based on our results, in complex cases where grade C ACC, VCC, and DDSP occur simultaneously, alternatively a ventriculocordectomy could sufficiently decrease the negative pressure and therefore might prevent the soft palate from having a tendency to become displaced dorsally.

A characteristic abnormal respiratory noise of racehorses during DDSP is the gurgling sound [20], but the functional disease can also stay silent or occasionally generate coughing [10]. In our case series, each horse was coughing during DDSP, which could be explained by hypersensitivity of the airways due to URT and/or LRT inflammation. The absence of the gurgling sound in sport and pleasure horses might be explained by the fact that their expiratory airflow does not reach a speed at which the free border of the soft palate resonate in the same way like in racehorses, as reported in the study by Van Erck–Westergren [10].

LHP is a distal axonopathy of the recurrent laryngeal nerve with clinical manifestation predominantly (95%) on the left side. Performing exercising endoscopy plays an important role in understanding LHP cases. First of all, it is possible to observe whether the condition worsens during exercise or alternatively if it gets compensated during high-intensity work. Moreover, even in those cases where we observed complete paralysis (grade 4), which cannot change during work, exercising endoscopy still plays a role by making it possible to gather information about VCC, which is commonly seen in horses with LHP and can be exclusively observed during exercise [1]. Severe manifestations are common in sport horses, which can be explained by the progressive nature of the disease, which gets increasingly severe with age.

In those of our cases where a significant ACC occurs during exercise and leads to abnormal respiratory noise, it is rare that the resting examination remains subclinical; however, LHP cannot be completely ruled out by resting endoscopic examination as it is documented in our case series and other cases described in the literature [21–23].

It is debated whether poll flexion impacts LHP. Rider intervention with poll flexion is thought to have an effect on laryngeal function and stability in sport horses [10]. According to another study [24], there is no correlation between laryngeal function and neck flexion. In one of our cases, we found that head and neck flexion significantly increased the collapse of the arytenoids. This case was a typical poll flexion–induced bilateral ACC with the simultaneous occurrence of VCC. The pathogenesis of this disorder is not fully understood. It is suspected that the underlying cause is not the distal axonopathy of the recurrent nerve but most likely a conformational change associated with poll flexion, when a more rostral position of the larynx occurs [25,26].

Exercise-induced pulmonary hemorrhage is a common disorder of racehorses [27], but it is not an exclusive characteristic of Thoroughbreds and standardbreds. Two of our sport horses had EIPH. In both cases, besides the hemosiderophage-positive BAL fluid, there were outstanding URT obstructions (LHP and VCC) observed. Regarding the relation of LHP and EIPH, it has been proposed that a horse may need less strenuous exercise for the development of EIPH with more severe URT obstruction [28]. Another study suggests that inspiratory obstruction in exercising horses causes an increase in transmural pulmonary capillary pressure gradient. This may contribute to loss of capillary integrity and lead to the rupture of the pulmonary capillaries [29].

The recently published consensus statement on EIPH does not examine the relationship or the possible relationship between the URT and EIPH. We are highlighting that the evidence on this association is rather weak because of the few published data regarding it [30].

According to the theory that EIPH is related to URT obstruction, the diagnosis and treatment of URT obstruction are essential in these cases. From the two cases where EIPH and LHP appeared simultaneously, one also had IAD. In cases such as this, our conclusion is that reducing inflammation of the LRT should be a priority during initial treatment because both URT obstruction and EIPH can be associated with IAD.

Even though LHP is a typical feature of large horses, in our caseload, ACC appeared in two ponies with severe poor performance. Initially, we started to treat the simultaneous LRT obstruction, which effectively improved the performance of the horses and decreased the PI, which is commonly seen in ponies. There is a possibility that simultaneously occurring PI and IAD might explain the LHP, which was more visible in these cases than what is usual in ponies. We are still investigating whether a sport or hobby horse's performance would be affected by an intermittent grade B ACC and VCC. Based on our search of the literature, this question has not yet been fully addressed in previous studies.

In all cases of dynamic PHC, there was evidence of decreased pharyngeal diameter visible on the OE image, although in less severe cases, this feature only appeared when the horse became fatigued. The abnormal respiratory sounds increased in parallel with poll flexion of the neck or fatigue of the horse. Rider modification with a less intensive poll flexion could be recommended in such cases. The surgical option is resection of the salpingopharyngeal fold [31].

By measuring plasma lactate levels—in a population where anaerobic state due to the intensity of the work is unlikely to appear—our goal was to investigate if a severe URT obstruction may cause increased lactate levels secondary to a suspected arterial hypoxemia during exercise, even if the workload is not excessive. In contrast to racehorses and Grand Prix sport horses [32], measurement of the plasma lactate levels was not informative in our cases, and the anaerobe–aerobe margin (4 mmol/L) was never exceeded. The significant decrease of exercising plasma lactate levels compared with resting levels could be explained by increased clearance during exercise.

Even in cases where severe or multiple obstructions were observed, owners might not perceive poor performance, which could be explained by the difficulties of objective performance measurement in sport horses by both the owner and the veterinarian.

5. Conclusions

Even a very small functional change in the URT can lead to poor performance in racehorses, which usually manifests at strenuous exercise. However, in sport horses, even a severe URT obstruction might not be obvious to the owner. Hence, it is essential to find an objective way to measure poor performance in sport horses.

Although the management of DDSP must be tailored to the cause, the treatment of LHP is independent of the underlying cause.

The weakness of the report is that because it is a clinical study, only those examinations could have been performed which were necessary for diagnostics.

We suggest that the use and/or discipline of the horse should be taken into account, when evaluating configuration problems of the URT; for example, in racehorses, a caudally and ventrally positioned larynx is disadvantageous, whereas in sport horses, the rostral position of the larynx can lead to URT obstruction during poll flexion.

It is important to treat the URT and LRT as a single unit because LRT disorders can often cause URT functional disease (e.g., RAO–DDSP), although URT obstructions could be a factor in LRT problems (LHP–EIPH).

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5.2. CHAPTER

Asthmatic disease as an underlying cause of dorsal displacement of the soft palate in horses

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Original Research

Asthmatic Disease as an Underlying Cause of Dorsal Displacement of the Soft Palate in Horses

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A R T I C L E I N F O

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A B S T R A C T

It is important to treat the upper and lower respiratory tracts as a single unit, as lower respiratory tract diseases can often cause upper respiratory functional disorders, whereas upper respiratory obstructions could be a factor in lower respiratory problems. The present study aimed to investigate the hypothesis that asthmatic diseases may be an underlying cause of dorsal displacement of the soft palate in horses. Pleasure or sport horses (n = 57) with a history of asthmatic disease were incorporated in the study. All horses were examined in the exacerbation phase of the asthmatic disease. Bronchoalveolar cytology and tracheal lavage bacteriology were performed in all cases. The upper respiratory tract was evaluated at rest in all horses and during exercising endoscopy in 11/57 with severe equine asthma. Binomial tests with $P \leq .05$ significance were used to establish estimated intervals of the measured frequencies of dorsal displacement of the soft palate (DDSP) occurring in the studied groups. It was observed that more than 60% of horses with mild or moderate equine asthma and more than 79% of horses with severe equine asthma are presented with DDSP during resting endoscopy examination. During the exercising endoscopy, DDSP was detected in all cases of severe equine asthma. These findings support the proposed hypothesis that DDSP was common in horses with equine asthma. Both increasing negative pressure in the airways due to bronchoconstriction and inflammatory processes could be factors in the development of DDSP. The consequent step would be to investigate the same population of horses in the remission phase of the equine asthma.

1. Introduction

The one airway, one disease concept has been advocated in human medicine [1,2]. Furthermore, it has also been investigated in equine medicine, whether the relationship between upper and lower airways described in humans could be applied to horses [3].

In a study from 2011, it was proposed that upper and lower airways were independent in terms of severity of inflammation [3]. It has been proposed that pharyngeal inflammation was not associated with changes in the tracheal cytology [4] or in the bronchoalveolar lavage (BAL) cytology [5]. However, several studies established other possible associations between the upper and the lower respiratory tract. Regarding the relation of upper airway obstruction—recurrent laryngeal neuropathy—and exercise-induced pulmonary hemorrhage, it has been proposed that

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Conflict of interest statement: None of the authors have any conflict of interest to declare.

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horses with more severe upper airway obstruction may need less strenuous exercise for the development of exercise-induced pulmonary hemorrhage [6,7]. It was also demonstrated in another study that an upper airway obstruction in exercising horses causes an increase in transmural pulmonary capillary pressure gradient [8]. This may result in the loss of capillary integrity and lead to the rupture of the pulmonary capillaries and consecutive epistaxis.

Exercise-induced pulmonary hemorrhage is a common disorder of racehorses [9], but it is not an exclusive characteristic of Thoroughbreds and Standardbreds, as it may also appear in horses performing less strenuous exercise [10]. In these cases, the origin is the mechanism caused by the upper airway obstruction described previously.

A further example for the interplay between the upper and lower airway disorders had been demonstrated in sport horses, where it was concluded that the palatal instability or nasopharyngeal collapse was significantly affected not just by the presence of the upper (pharyngeal), but the lower airway inflammation as well [11]. Finally, it was suggested—in our preliminary study—that equine asthma may cause dorsal displacement of the soft palate (DDSP) [12].

The present study aimed to investigate the hypothesis that asthmatic diseases might be an underlying cause of dorsal displacement of the soft palate in horses. Another goal was to investigate the clinical manifestation of DDSP correlated to equine asthma syndrome.

2. Material and Methods

2.1. Horses

This is a retrospective evaluation of the findings from 57 horses ranging in age from 4 to 21 (11.3 ± 3.2) years. The study was restricted to pleasure and sport horses (competing at the national level) referred for respiratory tract examination due to suspicion of equine asthma. In the history, one or more of the following symptoms were reported: chronic or intermittent cough, nasal discharge, poor performance, increased respiratory efforts, delayed recovery of respiratory rate after exercise, and exaggerated respiratory effort during work.

Owners gave consent for the inclusion of their animals' results in the study.

2.2. Resting Endoscopy

After recording the medical history and performing a physical examination, all horses underwent a resting endoscopy. The scope was passed through one of the nostrils; to handle the horse, a nose twitch was applied. The morphology and the function of the larynx and pharynx were investigated. Nasal occlusion test was performed to challenge the upper airway with more negative pressures during resting video-endoscopic examination, to mimic pressure changes that might occur during intense exercise [13].

Mucus score of the trachea was determined based on methods of Gerber et al., where grade 0 = no visible mucus, grade 1 = single to multiple small blobs of mucus, grade 2 = larger but non-confluent blobs, grade 3 = confluent or stream forming mucus, grade 4 = pool forming mucus, and grade 5 = profuse amounts of mucus) [14]. Excess mucus in the tracheobronchial tree (grade >2 for sports/pleasure horses) may reveal equine asthma syndrome [15]. Large amounts of mucus (grade 4–5) can be specific for severe asthma but could certainly also be caused by other airway diseases in a random population of horses [14].

2.3. Sampling of the Airways

Bronchoalveolar lavage and trachea lavage (TL) were also performed under sedation with detomidine (0.01–0.02 mg/kg, Domosedan, Orion Corporation) and butorphanol (0.01–0.03 mg/kg, Morphasol, aniMedica GmbH), to have a definitive diagnosis of equine asthma (BAL cytology) and to exclude bacterial infection of the respiratory tract (TL bacteriology).

For the BAL fluid cytology, 250–300 mL of 0.9% saline (physiological) solution was infused via the endoscope (350 cm long endoscope was used with EQUIVET Endoscope Flushing Catheter/2.3 mm × 400 cm/) or BAL catheter (EQUIVET B.A.L. catheter 240 cm). Based on published data, BAL fluid cytology values of >10% neutrophils, >5% mast cells, and >5% eosinophils were considered as mild/moderate equine asthma, while the cut off value of severe equine asthma were >25% neutrophils. The importance of BAL fluid cytology was established in light of the history, clinical examination, and endoscopic findings in each case [15].

For the collection of the TL, 20 mL of sterile 0.9% was injected through the lumen catheter (EQUIVET Endoscope Flushing Catheter/2.3 mm × 400 cm/) which was advanced to the trachea through the biopsy channel of the endoscope. Bacterial culturing was performed from the TL to investigate if there is a bacterial infection in the background of the respiratory tract signs. In addition, in 48 cases, TL cytologies were also performed, as it has been described in a newly reported study, it may be more specific and more sensitive compared with BAL fluid cytology [16]. A cutoff value of 20% was used to detect airway inflammation, eosinophils, and mast cells of TL cytology were not taken into account during the diagnostics of equine asthma syndrome.

2.4. The Classification of Horses

Based on the history and clinical signs of the horses, the tracheobronchial mucus score, the BAL cytology (and the TL cytology in 35/57 cases) the horses were divided into groups of mild/moderate or severe equine asthma. All horses with positive culturing of TL were excluded from the study. It was also taken into account whether the horses developed DDSP during resting endoscopy examinations. Based on these considerations the following groups were established:

Group 1. Severe equine asthma.
Group 2. Severe equine asthma and DDSP.
Group 3. Mild and moderate equine asthma.
Group 4. Mild and moderate equine asthma and DDSP.

2.5. Overground Endoscopy

Overground endoscopy (OE) examination was also performed with Dynamic Respiratory Scope (Optomed, DR v3, Les Ulis, France), saddle pad version in 11 horses from group 2 (severe equine asthma). The scope was passed from one of the nostrils; to handle the horse, a nose twitch was applied, and no sedatives were used. OE was performed in an outdoor arena. The horses were ridden by their usual riders, who were instructed to exercise the horses as usual during OE. Exercising endoscopy and concurrent respiratory noise were recorded.

In two horses after the OE test, 0.02 mg/kg bwt atropine was administered intravenously; after waiting 10 minutes, a second OE was performed and evaluated if any significant change was present [17]. This examination aimed to evaluate the upper respiratory tract after decreasing lower airway obstruction, which in turn decreased the negative pressure.

Binomial tests (Clopper-Pearson method) with $P \leq .05$ significance were used to establish estimated intervals of the measured frequencies of DDSP occurring in the studied groups.

3. Results

This report is an evaluation of the findings from 57 horses with equine asthma. Mild or moderate equine asthma was diagnosed in 25 horses. Severe equine asthma was diagnosed in 32 horses. The horses with positive bacterial culture from the trachea lavage were excluded from the study. Therefore 22 mild/moderate and 31 severe asthmatic cases were included in the present study.

During the resting endoscopy examination, 18/22 (59.7%–94.8%, binomial test at 95% CI) horses showed DDSP in the group of mild or moderate equine asthma, and 29/31 (78.6 %–99.2 %, binomial test at 95% CI) horses showed DDSP in the group of severe equine asthma, respectively. Overall binomial tests at 95% confidence intervals demonstrated that more than 60% of horses with mild or moderate equine asthma and more than 79% of horses with severe equine asthma show DDSP during resting endoscopy examination. The billowing of the soft palate appeared spontaneously and was not a result of the occlusion test. The summary of the data from the resting evaluation can be found in Table 1.

Eleven horses from group 4 were investigated with OE. In this group, severe equine asthma and dorsal displacement of the soft palate were already diagnosed previously. All horses (11/11) within this group performed DDSP during the OE (71.51%–100.00%, binomial test at 95% CI). In addition, a second OE was performed on 2 of these horses after the intravenous administration of atropine. No significant changes were visible; both horses performed DDSP again. During OE all horses were coughing intensively, simultaneously with the displacement (71.5%–100.00%, binomial test at 95% CI), no other typical abnormal respiratory sounds were detected during DDSP. In accordance with the owner's opinion, the use of OE did not alter the horses' performance and was well tolerated by each animal. The summary of the data from the OE examination can be found in Table 2.

4. Discussion

Identifying the definite cause of DDSP may be challenging, but since treatment of DDSP must be tailored to the cause, it is fundamental to find an objective way for defining the etiology of this upper respiratory tract functional problem. This is a topic that both addresses and is relevant to current issues in veterinary science [18,19].

In the caseload of the present study of sport and pleasure horses, it is unlikely that the etiology of the DDSP developed secondary to any of the intrinsic or extrinsic causes previously described [18]. Intrinsic causes may involve neuromuscular weakness of the upper airways secondary to infections or structural deformations (subepiglottic cysts, granuloma, epiglottitis, epiglottic chondritis, etc.) in the pharynx [20]. Intrinsic origin is unlikely in the cases of this study because there were no structural deformations observed in the case series (structural origin). To exclude neuromuscular weakness due to an upper respiratory infection, horses were excluded if the TL culturing was positive.

Exercise-induced DDSP is related to the extrinsic palatal musculature (thyrohyoid muscle), and it is most commonly found in young racehorses. In these cases, fatigue of thyrohyoid muscle is hypothesized as the main factor leading to DDSP. In this study of pleasure and sport horses, the DDSP was observed commonly already at rest and/or low-intensity work and it did not seem to be related to muscle fatigue or exercise. From a diagnostic point of view, it is an important question whether the resting endoscopic examination can be expected to yield the same result as the exercising examination. As with other aspects of DDSP, the answer depends on the cause of the disease. In particular, it is described in the literature that the resting endoscopic examination in case of extrinsic origin is insensitive [21], however, in the cases caused by asthmatic disease in the present study, resting examination was often satisfactory to detect the problem. The current standard surgical treatment for DDSP (laryngeal tie-forward) was developed to pull the larynx in a more cephalic position and correct a dysfunction of the **thyrohyoid** muscle [22]. As per the theory above, this should not be performed in the caseload of the present study. In these cases, DDSP is presumably caused by equine asthma. An explanation of this pathomechanism, could be that the markedly increasing negative pressure driven by the lower respiratory tract obstruction, might lead to a simultaneous negative pressure increase in the upper respiratory tract resulting in a DDSP. Twenty percent of the total pulmonary resistance results from the intrathoracic airways, 50% from the nasal passage, and 30% from the remaining upper airways, during quiet breathing. The resistance of the lower airway is much less than that of the upper airway, and this can be explained by the sum of the cross-sectional areas of the bronchioles, which is much greater than the cross-sectional area of the trachea. Another possible reason for the difference is the airflow, which is laminar in these regions and more turbulent in the trachea [23–25]. Extrathoracic airways of a horse can collapse under compressive pressure, as a result of the large difference of pressure in the intraluminal space and the surrounding tissue during inhalation [26]. This phenomenon is more likely to occur when partial airway obstructions are present [24,26,27]. The importance of the cross-sectional area of the airway is highlighted by the relationship between airway radius and resistance such that when the radius of the airway is reduced to one-half, and the resistance is increased by 16-fold [28].

Table 2
Summary of the horses that were examined with overground endoscopy (dorsal displacement of the soft palate—DDSP).

Findings	Cases
Resting endoscopy—DDSP	n = 11
Overground endoscopy—DDSP	n = 11
Abnormal respiratory noise during exercise	Coughing simultaneously with DDSP (n = 11)
Atropine test	No improvement regarding the DDSP (n = 2)

Table 1
Number of horses in the study (dorsal displacement of the soft palate—DDSP).

Disorders	Number of horses	Number of the horses excluded from the study	Number of the horses after exclusion
1. Mild and moderate equine asthma	7	1	6
2. Mild and moderate equine asthma + DDSP	18	2	16
3. Severe equine asthma	2	0	2
4. Severe equine asthma + DDSP	30	1	29
Total	57	4	53

To investigate the theory of whether the DDSP was developed secondary to decreasing (more negative) inspiratory pressure, an atropine test was performed in 2 horses. Atropine is commonly used in research protocols to assess the reversibility of airway obstruction, and it is the most potent bronchodilator drug currently available for horses [29]. However, it may have gastrointestinal, cardiovascular, and neurologic side effects that limit its use in clinical settings [29].

The finding that the administration of atropine did not lead to any improvement of the upper respiratory obstruction (DDSP) suggests that the link between equine asthma and DDSP may not be exclusively associated with the bronchoconstriction. Similarly, as in the exacerbations phase of severe equine, asthma airway obstruction is the result of a combination of bronchospasm (as shown by a maximum intrapleural pressure change>15 cmH2O), excessive mucus secretion, and inflammation of airway mucosa [30]. The underlying mechanical links between equine asthma and DDSP remain to be tested. It is worth noting, that a related question was studied in humans, where a “spillover” mechanism was suggested as a possible explanation of the connection between human asthma and a particular upper airway functional problem (obstructive sleep apnea, OSA). The cause of this mechanism is the asthmatic process that can result in systemic inflammation, which in turn weakens the respiratory muscles. This is accompanied by central nervous system inflammatory responses that could impair protective mechanisms of pharyngeal upper airway patency and destabilize the central breathing controller. It is a feasible theory that a similar effect occurs in horses [31].

DDSP was appearing spontaneously during resting endoscopy, without induction of occlusion test, which also suggests that change in the pressure gradient is not the only predisposing factor in the development of the disorder.

In the case series of the present study, each horse was coughing during DDSP. The absence of the typical gurgling sound in racehorses might be explained by the fact that their expiratory airflow in the cases of sport and pleasure horses does not reach a speed at which it could make the free border of the soft palate resonate, as this has been described already in literature [11].

In the cases of the present study, the primary treatment of equine asthma (environmental management and medical treatment) is suggested. The consequent step would be to evaluate the effect of treatment and environmental change and investigate the same population of horses in the remission phase of the disease.

5. Conclusion

The present study proposes that equine asthma commonly results in DDSP in pleasure horses. It is suggested that DDSP is not exclusively associated with the increasing negative pressure driven by the lower respiratory tract obstruction but rather tailored to the combination of the bronchospasm and inflammation of airway mucosa. A primary treatment of the lower airways is suggested for the cases in the present study. Further investigation is needed to confirm the hypothesis of this study in the remission phase of the equine asthma.

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5.3. CHAPTER

Evaluation of overground endoscopy findings in Colombian Criollo Paso horses

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Original Research

Evaluation of Overground Endoscopy Findings in Colombian Criollo Paso Horses

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A B S T R A C T

The dynamic upper airway functional (URT) problems of Colombian paso horses (CPH) have not been investigated in literature up to date. These horses perform special walking gaits with high poll flexion of the neck. Our goal is to evaluate the upper airway mechanics in CPH, showing abnormal respiratory sounds and poor performance during exercise. Resting and overground endoscopy was performed in 40 CPHs. Statistical analyses were performed using the sciPy package. One-tailed Fisher exact tests were used to check for positive contingency between each pair of upper respiratory tract disorder ($P < .05$). Arytenoid cartilage collapse was observed in 35 of 40 cases during exercise. Among these, dynamic laryngeal collapse (DLC) was the most significant finding, but ventromedial luxation of the apex of the corniculate process of the arytenoid and recurrent laryngeal neuropathy was also observed. Dorsal displacement of the soft palate was only detected in 4 of 40 cases. DLC was significantly associated with vocal cord collapse, nasopharyngeal collapse, and medial collapse of the margins of the epiglottis, and medial collapse of the margins of the epiglottis was associated with nasopharyngeal collapse. DLC is only a typical feature in some special breeds worldwide. We suggest that the extensive poll flexion and the relatively small laryngeal lumen and high intensitivity workload are the most important predisposing factors of DLC. Ventromedial luxation of the apex of the corniculate process of the arytenoid was overrepresented in our caseload, compared with other studies. Whereas, despite the intensive workload, dorsal displacement of the soft palate was relatively uncommon. We presume that this could also be tailored to the high poll flexion performed during the special gaits.

1. Introduction

Upper respiratory tract (URT) functional problems are common disorders among equine athletes and are often associated with poor performance and abnormal respiratory noise during exercise [1]. Recently, it has been described that the position of the neck can markedly impact the function and the mechanics of the recurrent laryngeal neuropathy (URT) in equestrian disciplines [2,3]. In a study, poll flexion during exercises was found to cause a significant increase in the mean peak inspiratory tracheal pressures. Poll flexion may therefore result in upper airway collapse in presumably normal horses and more significantly in horses with already weakened or fatigued neuromuscular function of the URT [4].

Endoscopy of the upper airways during rest is used to reveal anatomic abnormalities, and it may also predict some functional problems and provide information for understanding the causes of some functional diseases. Up to date, the gold standard method, to establish a definitive diagnosis of URT functional problems, is exercising videoendoscopy [5]. The advent of overground endoscopy (OGE) has enabled the monitoring of upper airway behavior in normal exercising conditions and the impact of rider intervention on the laryngeal and pharyngeal stability and function [6].

The Colombian paso horses (CPH), also called Colombian criollo paso horses are found throughout most of Colombia. They have been intensively selected for their gaits since the 1980s. The CPH has been divided into four lineages based on their natural gait (Colombian Paso Fino, Colombian Trocha, Colombian trocha-gallop, and Colombian trot-gallop) [7]. All horses registered in the studbook, Federación Colombiana de Asociaciones Equinas—Fedequinas, are allowed to participate in competitions in Colombia. An important feature of the CPH gait is the extensive

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collection and the high poll flexion of the neck (Fig. 1). This makes the gait even more exhausting to perform and may also be an important factor in the mechanics of the upper airways [7].

To the best of our knowledge, there are no published reports regarding the investigation of the dynamic upper airway functional problems in the CPH. Our goal is to evaluate the upper airway mechanics during OGE examination in CPHs showing abnormal respiratory sound and poor performance during exercise. Furthermore, our hypothesis is that the characteristics of the special walking gait and the high poll flexed neck may play an important role in the mechanics and the function of the URT of the CPH.

2. Materials and Methods

The study was restricted to CPHs referred for OGE with a history of poor performance and/or abnormal respiratory noise. A total of 40 CPH (Colombian Paso Fino /n = 8/, Colombian Trocha /n = 21/, Colombian trocha-gallop /n = 6/,and Colombian trot-gallop /n = 5/) were examined, ranging from 2 to 11,5 years (median 4 or mean 3,48 years) of age. Horses that had received any URT surgery before our evaluation were excluded. After the history, presenting complaint and physical examination findings were registered, and all horses underwent a resting and OG endoscopy performed with Tele-View Dynamic Equine Exercise Endoscope, TV-506 Articulating Model.

Owners gave consent for the inclusion of their animals' results in the study. Ethical approval for the study was granted by Medicina Veterinaria y Zootecnia—Universidad CES—Medellín (Approval number: 042/Ae-018).

2.1. Resting Endoscopy

Resting endoscopy was performed immediately before OGE. The scope was passed from one of the nostrils, to restrain the horse; during resting endoscopy, a nose twitch was applied and no sedatives were given. The URT anatomy and resting function of the larynx and pharynx and the nostril were assessed. Nasal occlusion was performed for 60 seconds, to simulate URT pressures achieved during exercise [8].

2.2. Exercising Endoscopy

Overground endoscopy was performed in an outdoor arena. The horses were ridden by their usual riders, after a 10–15 minutes long warm-up period the riders were asked to perform intensive work with the horses trying to reproduce the conditions of shows and/or competitions (exhibit a high animation of the gait and high poll flexion of the neck) (Fig. 2). The high intensity workload was maintained until fatigue or until it became evident, which URT functional disease was causing the poor performance or abnormal respiratory sounds. Whenever it was possible to perform, the riders were also asked to ride the horses with loose reins besides the high poll flexion that is normally performed at each CPH gate.

2.3. Videoendoscopic Evaluation

For the evaluation of the URT during resting and exercising endoscopy, a schematic grading system described in the study of Stand at al. and in other previous studies was used [9–13]. The data described in Table 1 were collected during the evaluation of URT functional problems during rest and exercise.

For any of functional problems during exercise present in Table 1 to be diagnosed, it had to be consistently present for >20 seconds, with the exception of dorsal displacement of the soft palate (DDSP), where 8-second maintenance of functional problem was sufficient for the diagnosis [13,14]. It was documented when asymmetry was observed between the left and right side. The video endoscopic examination was recorded for later slow motion and freeze frame analysis.

2.4. Data Analysis

A database was created using Microsoft Excel, and statistical analyses and graphs were performed using the SciPy (1.4.1) library of the Python programming language. Frequency of coexistence of

Fig. 1. A Colombian criollo paso horse performing the special walking gait (Photo: Franz Lagos).

Fig. 2. High poll flexion of the neck during overground endoscopy.

different dynamic URT disorders was investigated. For analysis of qualitative variables, frequency tables were evaluated with proportions for each one of the groups (in accordance with the disorders detected). The odds ratio was used as a measure of the association level with a confidence interval of 95%. For all statistical tests, a *P*-value lower than 0.05 was used to determine statistical significance. One-tailed Fisher exact tests were used to check for positive contingency between each pair of functional disorders.

3. Results

This is a retrospective study of the findings from the dynamic upper airway functional problems in Colombian criollo horses. The inclusion criteria were met by 40 horses (16 males, 24 mares). During the resting endoscopy, 17 cases showed a single or multiple disorders (Table 2). The exercising endoscopy evaluation revealed a very high prevalence (95% overall) of complex URT collapse. Cases in which unilateral or bilateral arytenoid cartilage collapse (ACC) and vocal fold collapse (VFC) occurred simultaneously or palatal instability appeared prior DDSP were considered as simple cases. All other combinations of URT obstructions were regarded as complex cases. Most (35 of 40) of the horses had ACC with the presence of one or more other abnormalities, and in 5 of 40 cases, there were no ACC found during OGE. Most commonly the ACC was bilateral (26 of 35)—dynamic laryngeal collapse (DLC) or ventromedial luxation of the apex of the corniculate process of the arytenoid (VLAC)—but unilateral ACC was also observed, only on the left side in 5 of 35 cases and only on the right side in 2 of 35 cases, and in 2 cases, unilateral left VLAC was visible (Fig. 3). Considering the whole endoscopic examination (resting endoscopy and OGE), only 10 of the ACC cases at OGE showed functional problems of the arytenoids at rest. Only 2 of the bilateral ACC cases developed bilateral collapse of arytenoids at rest and both were VLAC, whereas among the DLC cases, no bilateral functional problems of the arytenoids were detected at any of the cases at rest, only mild left arytenoid asymmetry (grade II/1 or II/2) was visible at rest in 5 cases. In the 9 cases where ACC appeared unilaterally during exercise, asymmetry of the arytenoids could be detected in 3 cases at rest.

All horses showing bilateral arytenoid cartilage collapses—DLC and VLAC—were performing poorly and made an excessive abnormal respiratory noise. None of the criollo horses could be investigated with extended neck and loose rain. The grade of the DLC collapse significantly differed during the warm-up phase—which was carried out already in extensive poll flexion—and during the high intensity workload at the end of the training session (Figs. 4 and 5). For the grade of DLC to be diagnosed, it had to be consistently present for longer than 20 seconds. One-tailed Fisher exact tests were used to check for positive contingency between each pair of functional disorders (Table 3). Calculations were carried out with the sciPy package. Table 4 lists the pairs where the test result was positive with $P < .05$. This demonstrates that DLC was significantly associated with VFC, nasopharyngeal collapse (NPC), medial collapse of the margins of the epiglottis (MCME), and MCME associated with NPC. The dynamic laryngeal collapses were bilateral but not always symmetrical in this evaluation. In our caseload, 4 (17%) of the DLCs were asymmetric.

In 4 (10%) cases, VLAC was observed, in 3 of 4 cases, the left corniculate process was ventral to the right, and in 1 case, the right was collapsing ventral to the left. Although there is one corniculate process preferentially collapsing ventral to the other in each case, we could distinguish between unilateral and bilateral VLAC. In both

Table 1
Disorders and grading systems used during resting and overground endoscopy.

Disorders	Resting Endoscopy	Overground Endoscopy
Recurrent laryngeal neuropathy[a]	I, II/1, II/2, III/1, III/2,III/3, IV	—
Arytenoid cartilage collapse[b]	—	Mild, moderate, severe
Dynamic laryngeal collapse	—	Mild, moderate, severe
Vocal fold collapse[b]	—	Mild, moderate, severe
Palatal instability	—	Mild, moderate, severe
Collapse of the nasopharynx[b]	Mild, moderate, severe	Mild, moderate, severe
Dorsal displacement of soft palate	Yes/no	Yes/no
Rostral displacement of the palatopharyngeal arch	Yes/no	Yes/no
Medial deviation of the aryepiglottic fold[b]	—	Mild, moderate, severe
Medial collapse of the margins of the epiglottis[b]	—	Mild, moderate, severe
Ventromedial luxation of the apex of the corniculate process of the arytenoid	Yes/No	Yes/no
Dynamic ventrorostral displacement of the dorsal laryngeal mucosa [c]	_	Yes/no

[a] Schematic grading scale for dynamic collapse of larynx and nasopharynx developed by Stand et al. (2012).
[b] Havemeyer grading system (Rakestraw et al.,1991).
[c] (Pollock et al., 2013).

Table 2
Total number of horses of each upper respiratory tract functional problem during resting and overground endoscopy.

Disorder	Left ACC/RLN	Right ACC	DLC	VLAC	VFC	DDSP	PI	NPC	MDAF	VRDDLM	MCME	RDPA
Exercise	3	1	24	4	34	4	12	12	14	2	30	9
Rest	7	1	0	2	0	7	11	8	0	0	0	3

Abbreviations: AAC, arytenoid cartilage collapse, DLC, dynamic laryngeal collapse; VLAC, ventromedial luxation of the apex of the corniculate process of the arytenoids; VFC, vocal fold collapse; DDSP, dorsal displacement of the soft palate, PI, palatal instability; NPC, nasopharyngeal collapse; MDAF, medial deviation of the aryepiglottic fold; VRDDLM, dynamic ventrorostral displacement of the dorsal laryngeal mucosa; MCME, medial collapse of the margins of the epiglottis; RDPA, rostral displacement of the palatopharyngeal arch.

of the unilateral cases, the left corniculate was collapsing ventral to the right, whereas in the bilateral cases, once the left and once the right arytenoid was collapsing ventral to the other. All VLAC were complex cases appearing simultaneously with one or more functional problems (Fig. 6).

In 2 DLC cases, the so-called *ventrorostral* displacement of the dorsal laryngeal mucosa (VRDDLM) was visible, during which a dorsal laryngeal mucosa progressively obscured the interarytenoid notch and dorsoaxial portion of the corniculate processes of the arytenoid cartilages at high-intensity work (Fig. 7). In 9 cases, rostral displacement of the palatopharyngeal arch (RDPA) was visible during exercise. In 3 cases, it was coappearing with DLC, in 3 cases with VLAC, and in 1 case with right ACC (Fig. 8).

There were only 5 of 40 cases in this evaluation not showing any functional problems of the arytenoids. Of these 5 cases, a diagnosis of DDSP, palatal instability, VFC, and medial deviation of the aryepiglottic fold was made (Table 1).

5. Discussion

The CPHs are the most important horse bred in Colombia. Several studies have confirmed the importance of evaluation of gait analysis, kinematics, and genetic variants between the CPH's gaits [7,15,16]. However, this is the first study evaluating the relationship between CPH's gaits and upper airway functional disorders. The specific and particular gaits are symmetric, walking gaits performed during high collection, with at least one limb in stance phase and with very short but extreme rapid stride frequency. All gaits of these horses exhibit a high animation and energy expenditure [7].

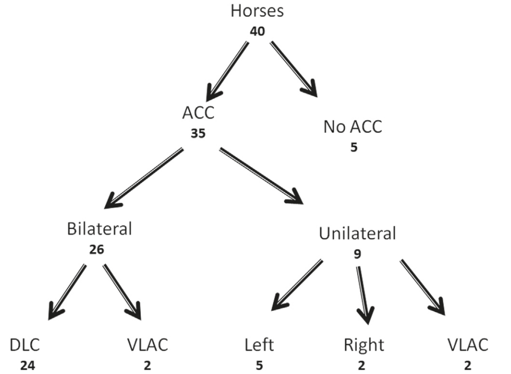

Fig. 3. The distribution of horses with and without arytenoid cartilage collapse (ACC). Abbreviations: dynamic laryngeal collapse (DLC), ventromedial luxation of the apex of the corniculate process of the arytenoids (VLAC).

Among ACCs, DLC was our most frequent finding in CPH, which is unusual, as ACC is most commonly caused by recurrent laryngeal neuropathy (RLN) [17]. RLN was only observed in 5 of our cases as the background of poor performance. There was evidence of bilateral collapse of the arytenoids documented in 26 of our cases. Among these bilateral ACC cases and also considering all other functional problems, DLC was our most significant finding, causing both extensive abnormal respiratory noise and poor performance. Although in most cases (95%) complex functional problems were observed, we concluded that in 60% of the horses DLC was the most important factor of the airway obstruction during exercise. DLC associated with poll flexion is a dynamic upper airway disorder in horses characterized by bilateral collapse of the arytenoid cartilages and vocal folds during head and neck flexion. The disorder is relatively newly described in literature and most frequently predisposed in the Scandinavian harness racehorses, namely in the Norwegian Coldblood Trotters and in the Standardbreds [11]. But it has also been reported in other breeds such as Icelandic horse with Tölting gait [18] and in other disciplines as well [19].

To investigate the significance of poll flexion in the development of the DLC (and other functional problems), riders were asked to ride the horses with loose reins besides the high poll flexion which is normally performed. The attempt to mimic extended neck carriage while performing the specific gaits by using long reins during OE failed, so we were unable to compare the two different neck positions of high poll flexion and extended neck carriage. However, we found a significantly higher grade of DLC during high-insensitive work when comparing with the warm-up phase of the training. Consequently, we hypothesize that although the poll flexion, which is an integral part of the CPHs gait, plays an important part in the development of the disease, the work insensitivity is also markedly influencing the manifestation of the DLC during OE. We also hypothesized that CPH consistently have smaller laryngeal lumens, which could potentially predispose these breeds to DLC due to the increased peak negative pressures which may occur.

None of the bilateral laryngeal dysfunctions were observed during rest, which is typical for this syndrome. In literature, DLC is

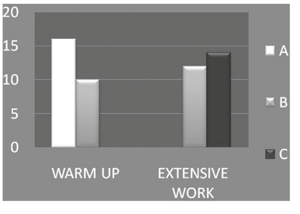

Fig. 4. The grade of the dynamic laryngeal collapse significantly differed during the warm-up phase and the high-intensity workload. In the warm-up phase, only grade A and grade B dynamic laryngeal collapse were observed, whereas during extensive work, grade B and grade C were found. (A: mild, B: moderate, and **C**: severe).

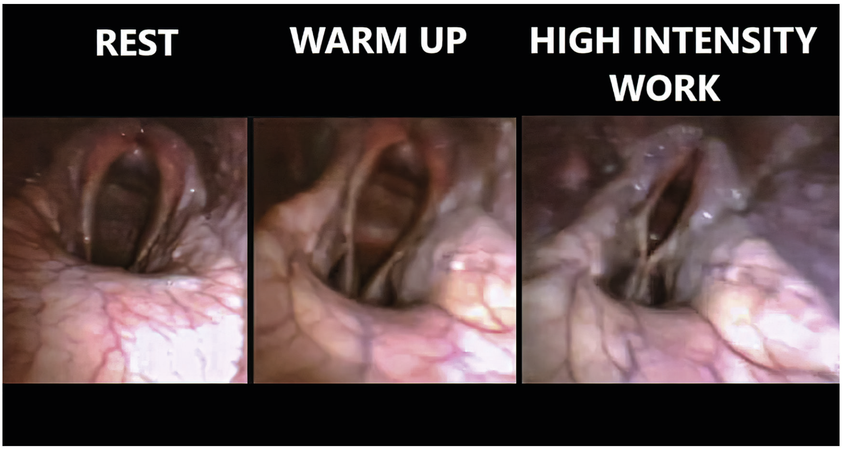

Fig. 5. The images show the common manifestation of dynamic laryngeal collapse in our caseload. Resting endoscopy: no functional change (left image), warm-up phase: mild collapse (middle image), extensive work: severe collapse (right image).

sometimes defined as a symmetric and bilateral collapse of the arytenoids and vocal cords during exercises. In our caseload 4 of 24 cases, there was some degree of asymmetry observed during the collapse, although the collapse was bilateral. In 3 cases, the asymmetry was more pronounced on the left and in 1 case, more on the right side. We conclude that laryngeal ultrasonography could be a valuable addition during the evaluation of laryngeal abnormalities in CPHs. In particular, when the bilateral arytenoid collapses are asymmetrical, we presume that it could be useful to exclude recurrent laryngeal nerve involvement (by the assessment of the relative echogenicity of the left and right cricoarytenoid lateralis muscle [20]) and to rule out laryngeal dysplasia (by the investment of the cricothyroid articulation/no gap visible/and the position of the thyroid cartilage/no dorsal extension visible/[21]).

Strong associations were observed between DLC associated with MCME, NPC, and between VFC. These associations were confirmed with a Fisher's exact test ($P < .05$).

MCME during OE appears to cause a visual obstruction of the airway in the laryngeal lumen. This hypothetically should result in increased turbulence and airflow velocity in the region. Because both structures are cartilaginous, it is possible that this disorder represents a form of generalized laryngeal hypoplasia, as it has been already described in Norwegian Coldblooded Trotters, which is another breed predisposed to DLC [13].

CPH showing DLC was often affected with moderate to severe collapse of the dorsal (and sometimes the lateral) nasopharyngeal wall as well. This abnormality has been reported as a potential cause of poor performance and abnormal respiratory noise in previous studies [10]. The cause of this URT condition is not known but is believed to be related to negative pressures in the nasopharynx during exercise and weakness of the stylopharyngeus muscles that dilate the dorsal nasopharynx [22]. We presume that both the intensive poll flexion and the dramatically increasing negative pressure develop because of the coappearing

Table 3
Coappearance of different dynamic upper respiratory tract disorders relative to each other in 40 criollo horses.

Disorders	Left ACC	Right ACC	DLC	VLAC	VFC	DDSP	PI	NPC	MDAF	VRDDLM	MCME	RDPA
Left ACC	**3**	0	0	0	2	0	1	0	0	0	0	0
Right ACC	0	**1**	0	0	1	0	1	0	0	0	1	0
DLC	0	0	**24**	0	26*	0	7	11*	9	2	25*	5
VLAC	0	0	0	**4**	3	1	0	1	2	0	3	3
VFC	2	1	26	3	**34**	1	9	11	13	2	29*	9
DDSP	0	0	0	1	1	**4**	3	0	1	0	1	1
PI	1	1	7	0	9	3	**12**	2	2	0	8	2
NPC	0	0	11	1	11	0	2	**12**	4	2	12*	0
MDAF	0	0	9	2	13	1	2	4	**14**	0	11	4
VRDDLM	0	0	2	0	2	0	0	2	0	**2**	2	0
MCME	0	1	25	3	29	1	8	12	11	2	**30**	8
RDPA	0	0	5	3	9	1	2	0	4	0	8	**9**

Abbreviations: AAC, arytenoid cartilage collapse, DLC, dynamic laryngeal collapse; VLAC, ventromedial luxation of the apex of the corniculate process of the arytenoids; VFC, vocal fold collapse; DDSP, dorsal displacement of the soft palate, PI, palatal instability; NPC, nasopharyngeal collapse; MDAF, medial deviation of the aryepiglottic fold; VRDDLM, dynamic ventrorostral displacement of the dorsal laryngeal mucosa; MCME, medial collapse of the margins of the epiglottis; RDPA, rostral displacement of the palatopharyngeal arch.
One-tailed Fisher exact tests were used to check for positive contingency between each pair of functional disorders. The pairs of disorders which were significantly associated ($P < .05$) are marked with *. In the diagonal of the table (bold) we indicated the total number of cases for each disease.

Table 4
List of the coappearance of upper airway functional problems where the result was positive with $P < .05$

Disorder 1	Disorder 2	Number of Horses	Significance
DLC	VFC	26	0.00078
DLC	NPC	11	0.021
DLC	MCME	25	0.000063
VFC	MCME	29	0.002
NPC	MCME	12	0.015

Abbreviations: DLC, dynamic laryngeal collapse; VLC, vocal cord collapse; NPC, nasopharyngeal collapse; MCME, medial collapse of the margins of the epiglottis.

Fig. 7. This image shows a dynamic ventrorostral displacement of the dorsal laryngeal mucosa and dynamic laryngeal collapse during overground endoscopy.

abnormalities (DLC and MCME), predispose the dorsal pharyngeal wall to collapse.

VLAC is an uncommon cause of upper airway dysfunction that may affect the performance of equine athletes. In our caseload, this disease appeared in 10% (4/40) of the cases, which was remarkably higher than found in previous studies [23,24]. The condition may be unilateral or bilateral, and it may be seen only at exercising endoscopy or during both resting and exercising endoscopy examination. One cartilage can subluxate beneath the other or the medial aspect of the apex of left and right cartilages can both be displaced ventrally [25].

VRDDLM is a newly described and rare abnormality identified during endoscopy of the upper portion of the respiratory tract of horses during exercise. It has been hypothesized that caudal retraction of the larynx may affect the laxity of laryngeal soft tissues [26], and this mechanism could reduce the tension on the mucosa dorsal to the arytenoids, allowing it for greater mobility and consequently, increasing the chance of displacement. Whether the abnormality is of clinical significance is difficult to determine because although it was recognized in horses presented for examination of abnormal inspiratory/respiratory noise and/or poor performance, it was identified concurrently with other recognized causes of abnormal inspiratory/respiratory noise and/or poor

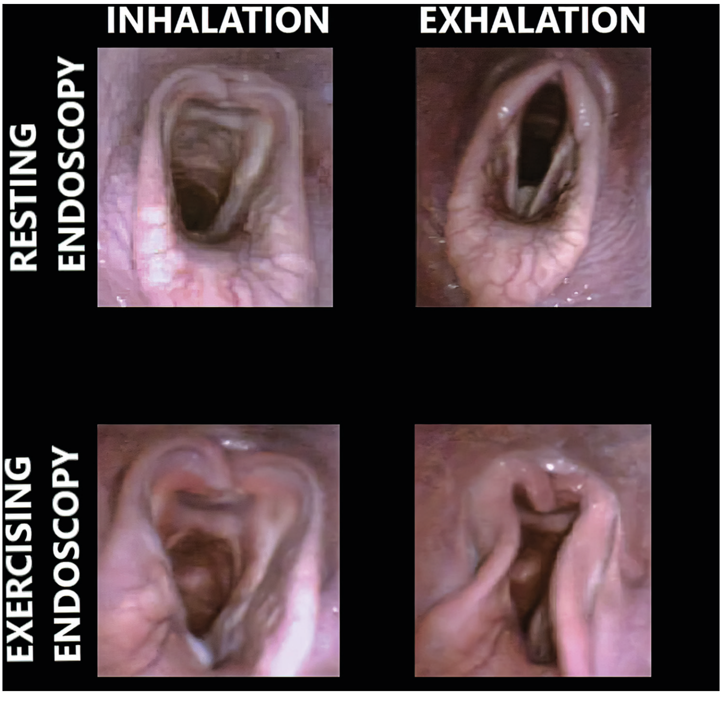

Fig. 6. Ventromedial luxation of the apex of the corniculate process of the arytenoids during rest and overground endoscopy (VLAC), and there is also medial deviation of aryepiglottic fold visible during exercise. There are marked differences visible on the inhalation and exhalation phase. Occlusion test was needed to induce VLAC during rest.

Fig. 8. Rostral displacement of the palatopharyngeal arch coappearing with: Dynamic laryngeal collapse (1. and 3. image), Medial luxation of the apex of the corniculate process of the arytenoids (2. image), Right arytenoid collapse (4. image).

performance [27]. We have also observed RDPA concurrently with luxation or collapse of the arytenoids. Although a grading system for RDPA has never been described in literature before, we propose that in most of our cases, RDPA could be described as a mild form of the disease. In each case with VRDDLM or RDPA, there was a concurrent ACC observed. Because right side (and sometimes left or bilateral) ACC can be a sign of laryngeal dysplasia, which is frequently associated with RDPA, it is important to distinguish between laryngeal mucosa displacement and RDPA in CPH and also to exclude laryngeal dysplasia by ultrasonography.

DDSP was only detected in 4 of 40 cases. The relatively low number of DDSP could be explained by the suspicion that the typical exercise-induced DDSP is not likely in the criollo athletes. We propose that the excessive poll flexion during the gaits of CPH could rather impede the manifestation of DDSP, whereas the extended neck and the high speed predispose to it in thoroughbred racehorse [28–30]. An intrinsic cause—neuromuscular weakness, structural deformations [31]—or lower airway origin [32] could be more likely to play a role in the development of this population.

5. Conclusion

The dynamic URT disorders have never been investigated in CPH before. DLC was our major performance limiting finding, which is an unusual disease and typical to only a few special breeds worldwide. We suggest that the extensive poll flexion, which is an integral part of the CPH's gait and the relatively small laryngeal lumen of these horses are the most important predisposing factors of DLC in our caseload.

Although the most important ACC is DLC in CPHs, other possible backgrounds of ACC (such as RLN or arytenoid dysplasia) should be excluded in each case. We propose that laryngeal ultrasonography should be routinely performed in CPH horses with DLC, especially in cases where the bilateral collapse of arytenoids is asymmetric and/or in cases where RDPA is coappearing.

Another rare laryngeal dysfunction VLAC was over-represented in our study, whereas despite the intensive workload of criollo horses, DDSP is relatively uncommon.

Acknowledgments

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6. GENERAL DISCUSSION

Even a very small functional change in the URT can lead to poor performance in racehorses, which usually manifests at strenuous exercise. However, in sport horses even a severe URT obstruction might not be obvious, which could be explained by the difficulties of objective performance measurement by both the owner and the veterinarian. The characteristics of URT functional disorders of non-racing horses significantly differ from the disorders of horses competing in non-racing disciplines. Findings of Hungarian sport and pleasure horses and Colombian sport/show horses were evaluated. In the Hungarian horse populations our studies (Study 1-2) enrolled warmbloods and ponies, in the study performed in Colombia (Study 3), Colombian Paso horses (CPH) were incorporated. The CPH, also called Colombian Criollo Paso horses are found throughout most of Colombia. They have been intensively selected for their gaits since the 1980s. The specific and particular gaits are symmetric, walking gaits performed during high collection, with at least one limb in stance phase and with very short but extremely rapid stride frequency. All the gaits of these horses exhibit a high animation and energy expenditure (Novoa-Bravo et al., 2018). All horses registered in the studbook, Federación Colombiana de Asociaciones Equinas – Fedequinas, are allowed to participate in competitions in Colombia. Several studies have confirmed the importance of evaluation of gate analysis, kinematics and genetic variants between the CPH's gaits (Duque et al., 2014; Jimenez et al., 2012; Novoa-Bravo et al., 2018). However, this is the first study calling attention to the relationship between CPH 's gaits and upper airway functional disorders.

The characteristics of DDSP and ACC − the most commonly occurring dynamic URT disorders − and other functional problems of the URT in non-racing disciplines will be discussed in the current chapter.

In our caseload of sport and pleasure horses in Hungary, it is unlikely that the etiology of the **DDSP** developed secondary to any of the intrinsic or extrinsic causes previously described in literature (Ducharme, 2009). It was observed that more than 60% of horses with mild or moderate equine asthma and more than 79% of horses with severe equine asthma are presented with DDSP during resting endoscopy examination. During the exercising endoscopy, DDSP was detected in all cases of severe equine asthma. These findings support the proposed hypothesis that DDSP can be tailored to equine asthma in our case series. As an explanation of this pathomechanism, we suggest that the markedly increasing negative pressure driven by the lower respiratory tract obstruction might lead to a simultaneous negative pressure increase in the upper respiratory tract resulting in a DDSP. To investigate the theory of whether the DDSP was developed secondary to decreasing (more negative) inspiratory pressure, we performed an atropine test in 2 horses. Our finding that the administration of atropine did not lead to any improvement of the upper respiratory obstruction (DDSP) suggests that the link between equine asthma and DDSP is not exclusively associated with the bronchoconstriction. Similarly, as in the exacerbations phase of severe equine asthma airway obstruction is the result of a combination of bronchospasm, excessive mucus secretion, and inflammation of airway mucosa (Barton and Gehlen, 2016). The underlying mechanical links between equine asthma and DDSP remain to be tested. It is worth noting that a related question was studied in humans where a „spill-over" mechanism was suggested as a possible explanation of the connection between human asthma and a particular upper airway functional problem (obstructive sleep apnea, OSA). The cause of this mechanism is the asthmatic process that can result in systemic inflammation, which in turn weakens the respiratory muscles. This is accompanied by central nervous system inflammatory responses that could impair protective mechanisms of pharyngeal upper airway patency and destabilize the central breathing controller. It is a feasible theory that a similar effect occurs in horses (Teodorescu et al., 2015). DDSP was appearing spontaneously during resting endoscopy, without induction of occlusion test, which also suggests that change in the pressure gradient is not the only predisposing factor in the development of the disorder.

The resting endoscopic examination in case of racehorses with extrinsic origin is insensitive (Lane et al., 2010), however in the cases caused by asthmatic disease in the current study, resting examination was often satisfactory to detect the problem. In our case series of study 2, each horse was coughing during DDSP (both at rest and at exercise). The absence of the typical gurgling sound in racehorses might be explained by the fact that their expiratory airflow in our cases of sport and pleasure horses does not reach a speed at which it could make the free border of the soft palate resonate, as this has been described already in literature (Van Erck, 2011).

The current standard surgical treatment for DDSP (laryngeal tie-forward) of extrinsic cause was developed to pull the larynx in a more cephalic position and correct a dysfunction of the TH muscle (Woodie et al., 2010). According to the theory above – that DDSP was not developing due to extrinsic cause – this surgical approach should not be performed in our caseload. In the cases of study 2, we suggest the primary treatment of equine asthma (environmental management and medical treatment).

Dorsal displacement of the soft palate was only detected in 4 out 40 cases in the CPHs. The relatively low number of DDSP could be explained by the suspicion that the typical exercise induced DDSP is not likely in the Criollo athletes. We propose that the excessive poll flexion during the gaits of CPH could rather impede the manifestation of DDSP, whereas the extended neck and the high speed predispose to it in thoroughbred racehorse (Cercone et al., 2019; Ducharme, 2009; Parente et al., 2002). An intrinsic cause − neuromuscular weakness, structural deformations (Holcombe et al., 1999) − or lower airway origin (Joó et al., 2015) could be more likely to play a role in the development of this population.

Among **ACC**-s, RLN was our most frequent finding in the sport and pleasure horse populations (Study 1), which is in accordance with findings in race horse populations (Joó et al., 2019).

Severe manifestations are common in sport horses, which can be explained by the progressive nature of the disease, which gets increasingly severe with age.

In those of our cases, where a significant ACC occurs during exercise and leads to abnormal respiratory noise, it is rare that the resting examination remains subclinical; however, RLN cannot be completely ruled out by resting endoscopic examination as it is documented in our case series and other cases described in the literature (Barakzai and Dixon, 2010). Two of the sport horses had EIPH simultaneously with RLN. It has been proposed that a horse may need less strenuous exercise for the development of EIPH with more severe URT obstruction (Cook et al., 1988). Another study suggests that inspiratory obstruction in exercising horses causes an increase in transmural pulmonary capillary pressure gradient. This may contribute to loss of capillary integrity and lead to the rupture of the pulmonary capillaries (Ducharme et al., 2010).

Among ACC-s, DLC − which is a poll flexion induced bilateral ACC with simultaneous VCC − was only observed in one single case during all examinations performed in Hungarian horse populations.

On the contrary, among ACC-s, DLC was the most frequent finding in CPH, which is unusual (Ducharme, 2016). Recurrent laryngeal neuropathy which is generally the most common cause of ACC was only observed in 5 of 40 cases as the background of poor performance in CPH. There was evidence of bilateral collapse of the arytenoids documented in 26 of 40 cases during exercise in CPH. Among these bilateral ACC cases and also considering all the other functional problems, DLC was our most significant finding (24 cases), causing both extensive abnormal respiratory noise and poor performance in CPH. None of the DLCs were observed during rest, which is typical for this syndrome. The disorder is relatively newly described in literature and most frequently predisposed in the Scandinavian harness racehorses, namely in the Norwegian Coldblood trotters and in the Standardbreds (Fjordbakk et al., 2008) and in the Icelandic horse with Tölting gait (Hanche-Olsen et al., 2010).

In 4 out of 24 cases of DLC-s there was some degree of asymmetry observed during the collapse, although the collapse was bilateral. In 3 cases the asymmetry was more pronounced on the left and in 1 case more on the right side. We have also observed RDPA in 9 out of 40 CPH, all appearing concurrently with ACC. VRDDLM - which is a newly described and rare abnormality identified during endoscopy of horses during exercise (Pollock et al., 2013) – was also detected in CPH. Since right side (and sometimes left or bilateral) ACC can be a sign of laryngeal dysplasia, which is frequently associated with RDPA, it is important to distinguish between VRDDLM and RDPA in CPH and also to exclude laryngeal dysplasia. Therefore, we conclude that laryngeal ultrasonography could be a valuable addition during the evaluation of laryngeal abnormalities in CPHs.

MCME was significantly associated with DLC in CPH, which appears to cause a visual obstruction of the airway in the laryngeal lumen. This hypothetically should result in increased turbulence and airflow velocity in the region. Since both structures (arytenoids, epiglottis) are cartilaginous, it is possible that this disorder represents a form of generalized laryngeal hypoplasia, as it has been already described in Norwegian Coldblooded Trotters (Strand et al., 2012).

VLAC is another uncommon type of ACC that appeared in 10 % (4/40) of the CPH, which was remarkably higher than found in previous studies (Barakzai et al., 2007; Dart et al., 2005). The condition may be unilateral or bilateral, it may be seen only at exercising endoscopy or during both resting and exercising endoscopy examination. One cartilage can subluxate beneath the other or the medial aspect of the apex of left and right cartilages can both be displaced ventrally (Priest et al., 2012).

In all cases of dynamic **NPC** in the Hungarian sport population there was evidence of decreased pharyngeal diameter visible on the OE image, but in less severe cases this feature only appeared when the horse became fatigued. The abnormal respiratory sounds increased in parallel with poll flexion of the neck or fatigue of the horse. Rider modification with a less intensive poll flexion could be recommended in such cases. CPH showing DLC were often affected with moderate to NPC as well. We presume that both the intensive poll flexion and the dramatically increasing negative pressure develop because of the co-appearing abnormalities, predispose the dorsal pharyngeal wall to collapse in CPH.

7. CONCLUSION

Reports of dynamic airway obstructions are primarily concerned with racehorse populations, while reports on such obstructions in sport horses and pleasure horses are scarce. Furthermore, the dynamic URT of Colombian Criollo horse, which is a show/sport horse with characteristic walking gaits, has never been investigated in literature before. A new possible etiology of DDSP was described during the evaluation of the Hungarian horse populations. Equine asthma commonly resulted in DDSP in pleasure horses. We suggest that DDSP is not exclusively associated with the increasing negative pressure driven by the lower respiratory tract obstruction but rather tailored to the combination of the bronchospasm and inflammation of airway mucosa. In these cases we suggest a primary treatment of the lower airways. Despite the intensive work load of Criollo horses DDSP is relatively uncommon. We propose that the excessive poll flexion during the gaits of CPH could rather impede the manifestation of DDSP of extrinsic cause.

Among **ACC**-s, RLN was our most frequent finding, while DLC was only found in one single case among the Hungarian sport and pleasure horse population. On the contrary, in the Colombian Criollo horses DLC was found to be the most common ACC. This latter finding is unusual and DLC is typical to only a few special breeds worldwide. We suggest that the extensive poll flexion, which is an integral part of the CPH's gait and the relatively small laryngeal lumen of these horses are the most important predisposing factors of DLC in our caseload of CPH. Another rare laryngeal dysfunction VLAC was over-represented in our study of CPH.

Although the most important ACC is DLC in CPH-s other possible backgrounds of ACC-s (like RLN or arytenoid dysplasia) should be excluded in each case. We suggest that laryngeal ultrasonography should be routinely performed in CPH horses with DLC. Especially in cases where the bilateral collapse of arytenoids is asymmetric and/or in cases where RDPA is co-appearing.

We suggest that the use/discipline of the horse should be taken into account, when evaluating configuration problems of the URT; for example, in racehorses a caudally and ventrally positioned larynx is disadvantageous, while in sport horses and show horses the rostral position of the larynx can lead to URT obstruction during poll flexion.

It is important to treat the upper and lower respiratory tracts as a single unit, since LRT disorders can often cause URT functional disease (e.g. Equine asthma – DDSP), while URT obstructions could be a factor in lower respiratory problems (RLN – EIPH).

8. NEW SCIENTIFIC RESULTS

Dorsal Displacement of the soft palate

1. Equine asthma commonly co-appears with dorsal displacement of the soft palate.
2. The origin of dorsal displacement of the soft palate is typically accompanied by lower airway obstruction and/or airway inflammation in sport and pleasure horses.
3. In cases where DDSP is co-appearing with equine asthma, the treatment should primarily focus on the lower airways.

The Colombian Criollo Paso horses

4. Among the Colombian Criollo horses the most significant functional problem is the dynamic laryngeal collapse.
5. Ventrorostral displacement of the dorsal laryngeal mucosa, which is a rare disease of the upper airways, should be distinguished from rostral displacement of the palatopharyngeal arch in the Colombian Criollo horses.
6. Ventrolateral luxation of the arytenoid cartilage was over-represented in Colombian Criollo horses compared with other studies.
7. Despite the intensive workload of Colombian Criollo horses DDSP is relatively uncommon.

9. SUMMARY

Dynamic upper respiratory tract (URT) obstruction is a common cause of abnormal airway noise and exercise intolerance in equine athletes. Several previous studies have documented that these disorders are underestimated or cannot be diagnosed during a resting endoscopic examination. To establish a definitive diagnosis of URT obstruction, exercising videoendoscopy is regarded as the 'gold standard' method

Reports of dynamic airway obstructions are primarily concerned with racehorse populations, while reports on such obstructions in sport-, show- and pleasure horses are scarce. In the studies carried out in the framework of my doctoral thesis, we investigated non-racing, sport- and pleasure horses in Hungary, alongside a special show horse, the Colombian Criollo horse.

<u>Study 1</u>

The aim of this report was to describe the results of URT diagnostic evaluation with overground endoscopy (OE) in sport and pleasure horses. The URT and plasma lactate levels were evaluated during rest and during overground endoscopic examination in 19 sport and pleasure cases. Horses performed their normal training session. When history and clinical examination suggested a lower airway obstruction, we performed bronchoalveolar lavage. Fisher's exact test was used to search for the likeliness of the coincidence of upper and lower airway obstructions. Sample averages of the lactate level intervals were calculated with a one-sample *t*-test at 0.95 confidence levels. Paired sample *t*-test was used to compare the averages

Dorsal displacement of the soft palate (DDSP) was diagnosed in 8/19 horses, which might have developed secondary to URT or lower respiratory tract inflammation or obstruction. None of the DDSP was an isolated finding.

Intermittent DDSP was also detected at rest in 4 cases. Recurrent laryngeal neuropathy (RLN) was diagnosed in 15/19 horses, 11 of which were complex cases with other types of URT obstructions. Severe pharyngeal collapse, suspected already at rest, was visible in two cases during exercise. In contrast, pharyngeal collapse diagnosed with nasal occlusion at rest in two cases was fully compensated under the rider. Plasma lactate levels significantly decreased during exercise.

All DDSP cases were suspected to be of inflammatory or obstructive origin, which is different from findings in racehorses, where extrinsic causes are more common. Resting endoscopic examinations were sensitive in cases of obstructive origin. RLN and pharyngeal collapse could not be predicted on the basis of findings at rest, and increased neuromuscular activity during exercise could compensate for the problem in less severe cases. Decreased levels of lactate could be explained by the increased clearance during exercise

Study 2

The present study aimed to investigate the hypothesis that asthmatic diseases may be an underlying cause of DDSP in horses. Fiftyseven pleasure or sport horses with a history of asthmatic disease were incorporated in the study. All horses were examined in the exacerbation phase of the asthmatic disease. Bronchoalveolar cytology and tracheal lavage bacteriology were performed in all cases. The upper respiratory tract was evaluated at rest in all horses and during exercising endoscopy in 11/57 with severe equine asthma. Binomial tests with $P \leq 0.05$ significance were used to establish estimated intervals of the measured frequencies of DDSP occurring in the studied groups. It was observed that more than 60% of horses with mild or moderate equine asthma and more than 79% of horses with severe equine asthma are presented with DDSP during resting endoscopy examination. During the exercising endoscopy, DDSP was detected in all cases of severe equine asthma. These findings support the proposed hypothesis that DDSP was common in horses with equine asthma. Both increasing negative pressure in the airways due to bronchoconstriction, and inflammatory processes could be factors in the development of DDSP. The consequent step would be to investigate the same population of horses in the remission phase of the equine asthma.

Study 3

Our goal was to evaluate the upper airway mechanics in CPH, showing abnormal respiratory sounds and poor performance during exercise. Resting and overground endoscopy was performed in 40 CPHs. Statistical analyses were performed using the SciPy (1.4.1) library of the Python programming language. One-tailed Fisher exact tests were used to check for positive contingency between each pair of functional disorders. Statistical significance was set at $P<0.05$. Arytenoid cartilage collapse was observed in 35 out of 40 cases during exercise. Among these, dynamic laryngeal collapse (DLC) was the most significant finding, but ventro-medial luxation of the apex of the corniculate process of the arytenoid (VLAC) and recurrent laryngeal neuropathy was also observed. Dorsal displacement of the soft palate (DDSP) was only detected in 4 out of 40 cases. Dynamic pharyngeal collapse was significantly associated with vocal fold collapse, nasopharyngeal collapse (NPC), medial collapse of the margins of the epiglottis (MCME) and MCME was associated with NPC. Dynamic pharyngeal collapse is only a typical feature in some special breeds worldwide. We suggest that the extensive poll flexion and the relatively small laryngeal lumen and high intensitivity workload are the most important predisposing factors of DLC. Ventro-medial luxation of the apex of the corniculate process of the arytenoid was over-represented in our caseload, compared to other studies. Whereas, despite the intensive workload, DDSP was relatively uncommon. We presume that this could also be tailored to the high poll flexion performed during the special gaits.

10. ÖSSZEFOGLALÁS

A dinamikus felső légúti funkciózavarok gyakran kóros légúti hangképzéshez és teljesítménycsökkenéshez vezetnek verseny- és sportlovakban. Habár egyes elváltozások diagnosztizálása, vagy legalábbis előrejelzése már nyugalmi helyzetben lehetséges, a felső légutak működési zavarainál gyakran csak a terheléses vizsgálattal kapható definitív diagnózis. Az overground endoszkóp (OGE) lehetővé tette, hogy a lovak felső légúti funkcionális zavarait természetes körülmények között, szokásos, lovas alatti munka során is megismerhessük. A dinamikus felső légúti elváltozásoktól szóló tanulmányok elsősorban versenylovak populációjával foglalkoznak, míg a sport-, hobbilovak tekintetében a szakirodalom még nagyon hiányos. Jelen doktori disszertációban, a Magyarországon vizsgált sport- és hobbilovak mellett, a speciális jármódú – sportlóként és lovas bemutatókon alkalmazott – kolumbiai criollo paso lovak felső légúti funkció zavarait vizsgáltuk.

<u>1. kísérlet</u>

Célkitűzésünk volt, a felső légúti funkciózavarok bemutatása sport- és hobbi lovakban overground endoszkópos vizsgálataink alapján. Tanulmányunkat teljesítmény csökkenést, illetve kóros hangképzést mutató lovakon végeztük. A felső légutakat és a plazma laktát szintjét nyugalomban és terhelés során vizsgáltuk. A lovak állandó lovasukkal, megszokott tréningjüket végezték. Amikor a kórtörténet, illetve a fizikális vizsgálat alapján felmerült egy szignifikáns alsó légúti szűkület lehetősége, akkor bronchoalveolaris lavage (BAL) mintát is vettünk a lovakból. Fisher exact tesztet alkalmaztunk, hogy elbíráljuk az alsó és felső légúti szűkületek közötti összefüggést. A laktát szint átlagértékeit 1 mintás t-próbával számoltuk, 0,95 konfidencia szint mellett. Az átlagok összehasonlítására pedig páros t-próbát alkalmaztunk. A lágyszájpad felső helyzetváltozását (dorsal displacement of the soft palate, DDSP) 8/19 ló esetében láthattuk. A DDSP 4 ló esetén már álló helyzetben is kialakult. Bal oldali gégebénulást (Recurrent laryngeal neuropathy, RLN) 15/19 lónál figyelhettünk meg, ezek közül 11-nél az RLN mellett egyéb felső légúti szűkület is megjelent. A garat súlyos fokú összeesését láthattuk 2 lónál munka közben, amely elváltozást előre jelzett az álló helyzetű vizsgálat. Két esetnél viszont – bár álló helyzetben megfigyelhettük a garat kollapszust – terhelés során teljesen kompenzálódott a folyamat. A plazma laktát szint minden esetben szignifikáns csökkenést mutatott. A szakirodalomnak megfelelően a DDSP és az RLN bizonyult a leggyakoribb rendellenességnek. Minden DDSP eset gyulladásra vagy légúti szűkületre volt visszavezethető, ami eltér a versenylovaknál tapasztaltaktól, ahol az extinsic eredet a gyakoribb. A nyugalmi vizsgálat az obstrukciós eredetnél bizonyult a legszenzitívebbnek. A DDSP kezelését az oktana alapján kell meghatároznunk. Az RLN és a garatkollapszus nem megjósolható az álló helyzetű vizsgálat alapján és a neuromuszkuláris aktivitás fokozódásának hatására kompenzálódott a kevésbé súlyos eseteknél. A laktát szint csökkenésére magyarázatot adhat a terhelés hatására beinduló klírensz mechanizmus.

2. kísérlet

Célunk volt annak vizsgálata, hogy állhat-e asztmatikus folyamat a DDSP hátterében, tehát az alsó és felső légúti elváltozások összefüggéseinek vizsgálata. Továbbá szintén célunk volt bemutatni az asztmatikus eredetű DDSP klinikumát. A vizsgálatba 57 olyan hobbi- vagy sportlovat vontunk be, amelyek a kórtörténetében asztmás betegség szerepelt. Minden lovat az asztmatikus folyamat exacerbációja során vizsgáltunk. A felső légutak álló helyzetű endoszkópos vizsgálatát, BAL citológiát és trachea lavage (TL) bakteriológiát minden esetben elvégeztük. Továbbá 11, súlyos asztmát mutató ló esetében, overground endoszkópos vizsgálatra is sor került. Végezetül, két ló esetében egy második OGE vizsgálatot is végrehajtottunk, miután a lovak intravénásan atropint kaptak. Binomiális tesztet (Clopper-Pearson módszer) alkalmaztunk ($P<0.05$) a DDSP gyakoriságának becslésére a vizsgált csoportokban. Megállapítottuk, hogy az enyhe vagy közepes asztmát mutató lovak több, mint 60%-ánál (18/22 ló, 59.7 – 94.8%, binomiális teszt, 95% CI), és a súlyos asztmát mutató lovak több, mint 79%-ánál (29/31 ló, 78.6 % – 99.2 %, binomiális teszt, 95% CI) DDSP is megfigyelhető volt a nyugalmi endoszkópos vizsgálat során. Tizenegy, súlyos asztmával diagnosztizált ló esetében, a terhelés során is elvégzett endoszkópos vizsgálatnál, pedig minden eseteben megfigyeltük a DDSP kialakulása. Az intravénás atropin beadását követően, a terheléses vizsgálat során, semmilyen szignifikáns változás nem volt megfigyelhető, mindkét lónál újra kialakult a DDSP. Az OGE során minden ló köhögött a DDSP-vel egyidejűleg (71.5% – 100.00%, binomiális teszt, 95% CI), semmilyen más tipikus kóros légzési hang nem volt megfigyelhető a DDSP kialakulása során. Eredményeink alátámasztják a feltételezésünket, miszerint a DDSP gyakori társjelensége az asztmatikus folyamatoknak. Véleményünk szerint, ilyen esetben a DDSP nem kizárólag az alsó légúti szűkület okozta negatív nyomásnövekedés következtében alakul ki, hanem inkább a bronchospasmusnak és a légúti gyulladásnak együttesen tulajdonítható. Ezekben az esetekben elsődlegesen az alsó légutak kezelését javasoljuk.

3.kísérlet

A világon elsőként, a kolumbiai criollo paso lovak felső légúti funkciózavarait is vizsgáltuk. Feltételezésünk az volt, hogy ezen lovak speciális jármódja ("walking gait") és kifejezett szárra állítása nagy hatással lehet a felső légutak mechanikájára. Összesen 40 criollo lovat vizsgáltunk álló és terheléses endoszkópia során is. A statisztikai elemzéseket Python programozási nyelv használatával, SciPy (1.4.1) könyvtárával végeztük. Egyoldalas Fisher-egzakt tesztet használtunk a pozitív kontingencia vizsgálatára ($P<0.05$), páronként összehasonlítva a felső légúti funkciózavarokat A kannaporc kollapszus 35/40 esetben volt megfigyelhető terhelés során, ezek közül a dinamikus gége kollapszus (dynamic laryngeal collapse, DLC) bizonyult a legjelentősebb elváltozásnak, de a kannaporc szarvnyúlvány csúcsának ventromedialis luxációja és RLN is megfigyelhető volt. A DLC megjelenése szignifikánsan köthető volt a hangszalag kollapszushoz, a garatkollapszushoz és a gégefedő szélének mediális kollapszusához. A DLC foka szignifikánsan romlott a terhelés intenzitásával. Két DLC esetében a gége dorsalis nyálkahártyaredőjének ventro-rostralis helyzetváltozását láthattuk. Kilenc esetben a palatopharyngealis ív rostralis helyzetváltozása volt megfigyelhető a kannaporc kollapszusok mellett. Lágyszájpad felső helyzetváltozását csak 4/40 esetben állapítottunk meg. A kolumbiai criollo lovak esetében a DLC bizonyult a leggyakoribb kannaporc kollapszusnak. Ez utóbbi eredmény szokatlan és a DLC tipikusan csak néhány lófajtában jelenik meg világszerte. Feltételezésünk szerint a criollo lovak esetében a DLC-re hajlamosító tényezők közé tartozik, egyrészt a kifejezett szárra állítás, másrészt az, hogy ezek a lovak relatíve kicsi átmérőjű gége lumennel rendelkeznek. Egy másik ritka gége diszfunkció, a kannaporc szarvnyúlvány csúcsának ventromedialis luxációja is felülreprezentált a criollo lovak alkotta ló populációban. Habár a legfontosabb kannaporc kollapszus a criollo lovak körében a DLC, javasoljuk a kannaporc kollapszus egyéb lehetséges háttereit (mint RLN vagy gége diszplázia) a diagnosztika során kizárni. Ennek érdekében gége ultrahang rutinszerű elvégzését ajánljuk DLC gyanúja esetén. Különös tekintettel azokra az esetekre, ahol kétoldali kannaporc kollapszus asszimetrikus, illetve ahol társjelenségként megfigyelhető a palatopharyngealis ív rostralis helyzetváltozása. A criollo lovak esetében az intenzív munka ellenére relatíve ritka volt a DDSP kialakulása. Feltételezzük, hogy a kifejezett szárra állítás, amely jellemző ezen lovak speciális jármódjára, inkább akadályozhatja az extrinsic eredetű DDSP kialakulását.

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13. PUBLICATIONS AND PRESENTATIONS

13.1. Scientific papers and lectures on the subject of the thesis

Peer-reviewed papers published in foreign scientific journals

Joó, K., Szenci, O., Bohak, Z., Povazsai, A., Kutasi, O., 2015. Evaluation of Overground Endoscopy Findings in Sport and Pleasure Horses. Journal of Equine Veterinary Science 35, 756–762.

Joó, K., Povazsai, A., Bohak, Z., Szenci, O., Kutasi, O., 2021. Asthmatic disease as an underlying cause of dorsal displacement of the soft palate in horses. Journal of Equine Veterinary Science 96,103308.

Joó, K., Duque, D., Vasquez, T., Parra, L., 2021. Evaluation of overground endoscopy findings in Colombian criollo paso horses. Journal of Equine Veterinary Science. Journal of Equine Veterinary Science 96, 103308.

Peer-reviewed papers published in Hungarian scientific journals

Joó, K., Nyerges-Bohák, Zs., Szenci, O., Kutasi, O., 2014. Endoscopic examination of dynamic upper respiratory tract disorders in horses. Literature review. Hungarian Veterinary Journal 323-334.

Joó, K., Németh, G., Bohák, Z., Tóth Luca, A., Szenci, O., Kutasi, O., 2019. Significance and possible aetiologies of arytenoid cartilage collapse in horses Literature review Hungarian Veterinary Journal 451-462

Most important presentations related to the topic of the thesis

Oral presentations

Joó, K., Kovács, M., Szenci, O., Bohak, Z., Povazsai, A., Kutasi, O., Asthmatic diseases as an underlying cause of dorsal displacement of the soft palate in horses. World Equine Airway Symposium, 13-15. July 2017. Copenhagen, Denmark

Joó, K., Sportélettan és teljesítmény - Alsó és felső légutak problémái. 24th Congress of the Hungarian Association of Equine Practitioners, 2-3. December 2016. Telki, Hungary

Joó, K., Kovács, M., Szenci, O., Bohak, Zs., Povazsai, A., Kutasi, O., A kannaporc kollapszus lehetséges eredetei lovakban, MTA Állatorvostudományok Bizottsága, Akadémiai beszámoló, 23-26. January 2017. Budapest, Hungary

Joó, K., Kovács, M., Szenci, O., Bohak, Zs., Povazsai, A., Kutasi, O., Overground endoszkópos vizsgálatok értelmezési nehézségei sport lovak esetében, MTA Állatorvostudományok Bizottsága, Akadémiai beszámoló, 26-29. January 2015. Budapest, Hungary

Joó, K., Kovács, M., Szenci, O., Bohak, Zs., Povazsai, A., Kutasi, O., Dinamikus felső légúti elváltozások lovakban: előtanulmány vizsgálati protokollok felállításához, MTA Állatorvostudományok Bizottsága, Akadémiai beszámoló, 23-26. January 2017. Budapest, Hungary

Joó, K., Sport- és hobbi lovak felső légúti funkciózavarai, Innovatív tudományos műhelyek hazai agrár felsőoktatásban, 27. November, 2017. Debrecen, Hungary

Joó, K., Szenci, O., Bohak, Z., Povazsai, A., Kutasi, O., The complex nature of dynamic upper airway obstructions,Young WEVA, 2nd International Vetcamp, 8-14. August 2014. Saarlouis, Germany

Poster presentation

Joó, K., Bohak Zs., Povazsai, A., Szenci, O., Kutasi, O., Difficulties in the evaluation of overground endoscopy findings in sport horses. 14th WEVA Congress, 8-10 October 2015. Guadalajara, Mexico

13.2. Most important publications not related to the topic of the thesis

Peer-reviewed papers published in foreign scientific journals

Joó, K., Bakonyi, T., Szenci, O., Sárdi, S., Ferenczi, E., Barna, M., Malik, P., Hubalek, Z., Fehér, O., Kutasi, O., 2017. Comparison of assays for the detection of West Nile virus antibodies in equine serum after natural infection or vaccination. Veterinary Immunology and Immunopathology 183, 1–6.

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Joó, K., Trúzsi, R., Kálmán, Cs., Jakab, Sz., Bába, A., 2021. The fundamentals of modern equine parasitology control, literature review. Hungarian Veterinary Journal 143, 131-144.

Bohák, Zs., **Joó, K.,** Tóthné Maros, K., Kovács, L., 2020. Heart rate variability measurements in equine exercise physiology Literature Review. Hungarian Veterinary Journal 142, 643-652.

Joó, K., Trúzsi, R., Lengyel, D., Jakab, Sz., Equine odontoclastic tooth resorption and hypercementosis. Hungarian Veterinary Journal (submitted to journal)

14. CURRICULUM VITAE

In 2013 dr. Kinga Joó obtained her doctor of veterinary medicine (DVM) diploma at the University of Veterinary Medicine, Budapest. During her university years she participated in externship programs three times: Universität Bern, Vetsuisse Fakultät, Pferdeklinik (2011 and 2012), University College of Dublin Veterinary Hospital, Equine Medicine and Surgery (2012).

Between 2013 and 2018 she was a member of MTA-SZIE Large Animal Clinical Research Group.

Between 2016 and 2020 she was a full-time student at the Doctoral School of Animal Science of Hungarian University of Agriculture and Life Sciences, Kaposvár Campus. She obtained the "New National Excellence Program of the Ministry of Human Capacities" three times and the Tempus Public Foundation, Campus Mundi International Internship Program two times (Equine Veterinary Clinic, Massey University, New Zealand /5 months/, Universidad CES, Medellin, Colombia /3 months/.

From 2014 she has participated in the theoretical and practical teaching of „Equine exercise physiology and sports medicine" and "Medical aspects of the equine gastrointestinal diseases" subjects at University of Veterinary Medicine, Budapest.

Since 2016 she participated in 15 scientific Conferences / Symposiums / Workshops (8 Hungarian and 7 International) from which she introduced her scientific work 10 times. Her publication list contains 8 first author peer-reviewed papers (5 in English and 3 in Hungarian). In 2019 she reviewed two articles for PLOS-ONE.

She was also the thesis supervisor for 5 (BSc. or veterinarian) students, from whom 2 participated in the Scientific Student's Conference (both won the Hungarian Association of Equine Practitioners Prize).