

Gross Anatomy of the Nose, Nasal Cavity and Larynx in the Pampas Deer (*Ozotoceros bezoarticus*, Linnaeus 1758)

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ABSTRACT

Available information on the anatomy of the respiratory system of the pampas deer (*Ozotoceros bezoarticus*, Linnaeus 1758) is scarce, so the aim of this work was to describe the upper respiratory tract anatomy of this species. The study was performed with 10 adult animals of both sexes and the study method was simple dissection. Pampas deer had a nasolabial plane different to the small domestic ruminants. The nasal cavity had the fundamental conformation of the ruminants with simple winding of the dorsal concha and double winding of the ventral one. The vomeronasal organ communicated directly with the oral cavity by the incisive duct. The larynx was located ventrally to the first two cervical vertebrae. The total length of the larynx was 52.76 ± 7.66 mm from the epiglottis to the cricoid cartilage. The dorsoventral length was 30.32 ± 3.71 mm. It is necessary to make detailed histological examinations of the distribution of the olfactory epithelium versus non-sensory epithelium within the nasal cavity. These data are essential to understand the function of the turbinates and the nasal cavity in general. In the same way, detailed studies of the physiology of the vomeronasal organ and larynx are necessary.

Keywords: Cervidae; Deers; Respiratory System; Ruminant.

1. Introduction

The pampas deer (*Ozotoceros bezoarticus*, Linnaeus, 1758) was a widespread species, originally distributed in the open grasslands (pampas) across eastern South America, from 5° to 41° S (Jackson and Langguth, 1987). However, the number of animals and populations declined during the last two centuries due to the loss of habitat, unregulated hunting, competition with cattle (Jackson and Giullieti, 1988), and transmission of cattle diseases (Jungius, 1976). There are small populations remaining in Argentina, Brazil and Uruguay, but the species is considered as near threatened by IUCN (González and Merino 2008). In Uruguay, there are two endemic subspecies (González *et al.*, 1998; 2002): *O. b. arerunguensis* (Salto, 31°65' S, 56°43' W) and *O. b. uruguayensis* (Rocha, 33°45' S, 54°02' W), different from the *O. b. bezoarticus*, *O. b. leucogaster*, and *O. b. celer*

previously described (Jackson and Langguth, 1987).

In previous studies in this species we described the papillae of the tongue by scanning electron microscopy, the gross anatomy of the gastrointestinal tract and its arterial vascularization (Pérez *et al.*, 2008; Pérez and Ungerfeld, 2012; Erdoğan and Pérez, 2013; Pérez *et al.*, 2017) and reproductive organs (Pérez *et al.*, 2013 a, b). Other of our studies were related to the arterial supply involve the distribution of the aortic arch (Pérez and Erdoğan, 2014), the adrenal gland (Erdoğan and Pérez, 2014), gastrointestinal (Pérez *et al.*, 2016) and pelvis with pelvic limbs (Vazquez *et al.*, 2018).

Most scientific knowledge about the anatomy of the respiratory apparatus of domestic ruminants is documented in a vast number of publications and in classic textbooks (Nickel *et al.*, 1987; Saber, 1983; Barone, 2010; König and

Liebich, 2015). In deer, Bisailon (1985) studied the larynx in white-tailed deer and more recently Frey *et al.* have performed physiological work in relation to vocalization in other ruminants (Frey *et al.*, 2003, 2006, 2007a, b). Frey's works initiated a path to correlate the anatomy of the organ with its phonation function. This author investigates the anatomy of the organ of phonation and acoustic behavior during the reproductive season in Ruminants such as red deer.

Our current knowledge of the respiratory system anatomy of non-domestic ruminants is based only in some descriptions about few of the near to 300 extant species. The information on the respiratory system of the pampas deer is null. The anatomical information obtained is interesting for future physiological or clinical studies that have been carried out in a similar way in other ruminant species (Frey *et al.*, 2003, 2006, 2007a, b, Stierschneider *et al.*, 2007). In this study we described the anatomy of the nose, nasal cavity and larynx, in order to increase the anatomical knowledge of these species.

2. Materials and Methods

In Uruguay, there is a population of pampas deer maintained in semicaptive conditions in a native fauna breeding station (Estación de Cría de Fauna Autóctona Cerro Pan de Azúcar, ECFA; 34°3' S, 55°1' W; altitude: ~ 200 m) (Ungerfeld *et al.*, 2008). This population was originated in 1982 from *O. b. arerunguensis* animals, and actually consists of approximately 80 animals. Ten animals (7 females and 3 males) that were found dead at the ECFA from causes unrelated to the respiratory tract, and were frozen until dissection, were used. The specimens were handled and treated according to the local Ethical Board guidelines of Universidad de la República (Uruguay).

The main method of study of the animals was simple macroscopic dissection. Pictures were taken with a Nikon digital camera. Terms were used in agreement with the *Nomina Anatomica Veterinaria* (2017).

3. Results

The bony support of the nose and the nasal cavity was formed dorsally by the nasal bones, laterally by the maxillary bones and ventrally by the palatine processes of the incisive, maxillary and palatine bones, that

formed the osseous support of the hard palate. The palatine bone occupied almost half of the surface, extending caudally from the first molar. The ethmoid and the vomer are also involved in the constitution of the nasal cavity next to the nasal conchae (Figure 12).



Figure 12; Left side view of the head of a female pampas deer after removal of the skin. 1: Laryngeal prominence; 2: Cricoid cartilage; 3: Trachea.

The upper lip had a little marked filter and in its medial parts it entered into the constitution of a pigmented nasolabial plane, black in all the animals. The philtrum divided the nasal plane. The surface of the nasolabial plane was subdivided into small irregular areas by shallow grooves. The dorsal part of the nasolabial plane that was located between the nostrils was smooth. The lateral parts of the upper lip on its outer face were white.

The nasal cavity itself began rostrally with the nasal vestibule. The nasal vestibule was always pigmented in black and continued caudally with the nasal cavity without a clear delimitation in the limit of the nose (Limen nasi). On the nasal vestibule and near to the limit of the nose we had the location of the nasolacrimal ostium, the terminal orifice of the duct of the same name.

The nasal cartilages were rostral to the nasal osseous opening formed by the nasal, incisive, and maxillary bones, and served as a support base for the nostril and nasal vestibule. The nasal vestibule was complemented by the mobile part of the nasal septum. These cartilages were mobilized by muscles that were involved in controlling the amount of air inhaled. We had the presence of the alar cartilage, the lateral dorsal and lateral ventral cartilages and the lateral and medial accessory nasal cartilages.

The movements of the nostrils and nasal vestibule were given by muscles that were inserted into the

bones and skin of the neighborhood. These were the dilator of the nostrils, the canine, and the nasolabial levator.

The nasal cavity, ended caudally in the choanae, openings on both sides of the nasal septum. This cavity was separated by the bony palate from the mouth and was elongated as the face. The median nasal septum (Figure 2) divided the nasal cavity into two symmetrical halves. The nasal cavity was described as a right half and a left half and each one had a roof, a floor, two walls (medial and lateral), and two extremities.



Figure 2; Sagittal section of the head of the pampas deer, medial view of the lefthalf 1: Nasopharynx; 2: Ethmoidal-conchae; 3: Middle nasal concha; 4: Dorsal nasal concha; 5: Ventral nasal concha; 6: Middlemeatus; 7: Ventral meatus; 8: Nostrils; 9: Hardpalate; 10: Soft palate.

The roof of the nasal cavity was a longitudinal leak under the lateral dorsal cartilage and nasal bone to the roof of the ethmoidal labyrinth (Figures 3, 4, 7).



Figure 3; Cross section of the nasal cavity, rostrocaudal

and medial view of the left side.1: Middle nasal concha; 2: Ventralnasal concha; 3: Middle meatus; 4: Ventral meatus; 5: Palatine sinus.

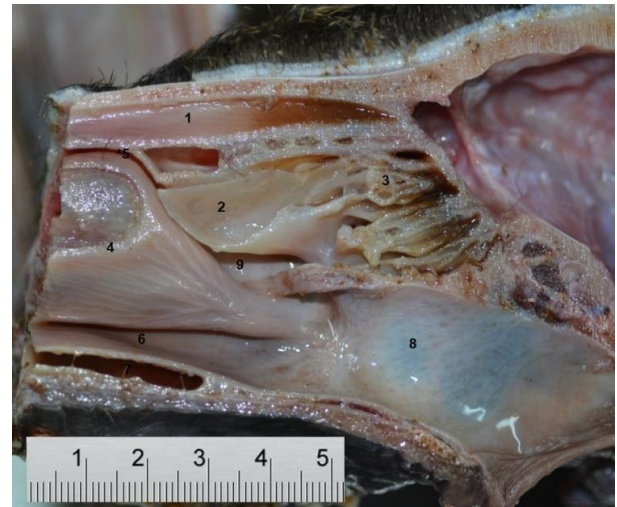


Figure 4; Cross section of the nasal cavity of pampas deer, caudal view.1: Dorsal nasal concha; 2: Middle nasal concha; 3: Ethmoidal concha; 4: Ventral nasal concha; 5, 9: Middle meatus; 6: Ventral meatus; 8: Nasopharynx.

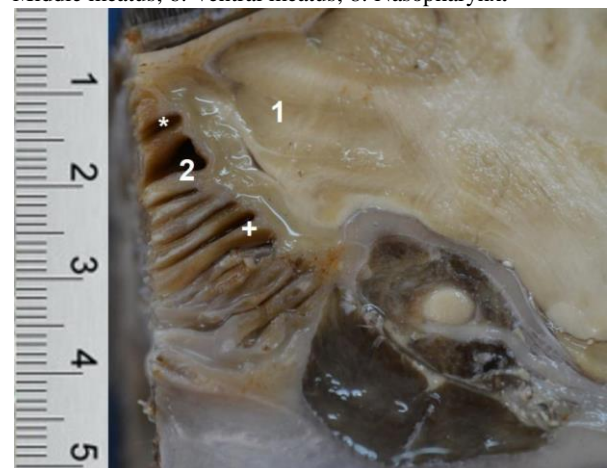


Figure 7; Sagittal section of the caudal half of the pampas deer head, medial view of the left side.1: Olfactory bulb; 2: Conchae and ethmoidal meatos; *: Meatos; +: Conchae.

The floor was wider than the roof, carried by the palate.

The rostral tip joined the nasal vestibule at the limit of the nose and the caudal extremity presented caudally in its dorsal part the ethmoidal labyrinth formed by the ethmoidal turbinates. The ventral part of this extremity was the nasopharyngeal meatus, which communicated with the opposite side because the nasal septum did not reach the caudal part of the cavity.

The medial wall belonged to the septum was ver-

tical and flat. The nasal septum began rostrally with a mobile cartilaginous part and had a ventral and caudal bony part. It was fixed to the palatine process of the incisive bone, the vomer and the perpendicular lamina of the ethmoid.

The lateral wall was oblique ventrolaterally, very irregular and anfractuous, showed the protuberance of the conchae. There were two groups of conchae, one rostral and one caudal. The rostral group was that of the dorsal and ventral nasal conchae (Figure 2, 3, 4, 5, 6, 8, 9, 10). The middle nasal concha was the most developed of the ethmoid turbinates that advanced cranially (Figures 2, 3, 4).

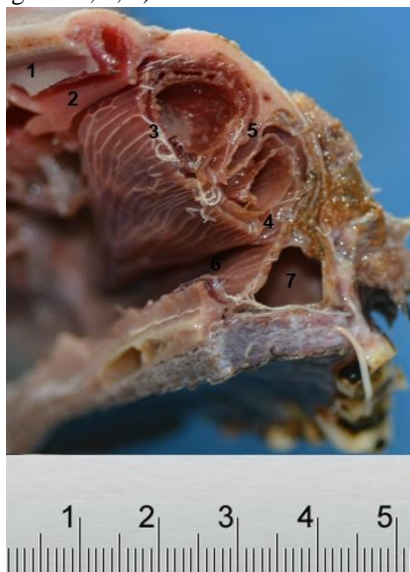


Figure 5; Cross section of the nasal cavity of pampas deer, rostral view.1: Nasal septum; 2: Dorsal nasal concha; 3: Dorsal lamina of the ventral concha; 4: Ventral lamina of the ventral concha; 5: Main lamina of the ventral concha; 6: ventral meatus; 7: Palatine sinus



Figure 6; Cross section of the nasal cavity of pampas deer, rostral view.1: Dorsal nasal concha; 2: Dorsal lamina of

the ventral concha; 3: Main lamina of the ventral concha; 4: Ventral lamina of the ventral concha.



Figure 8; Cross section of the nasal cavity of pampas deer, frontal view.1: Maxillary sinus; 2: Dorsal nasal concha; 3: Septum nasal 4: Dorsal lamina of the ventral concha; 5: Mainlamina of the ventral concha; 6: Ventral lamina of the ventral concha; 7: Ventral meatus; 8: Commonmeatus.

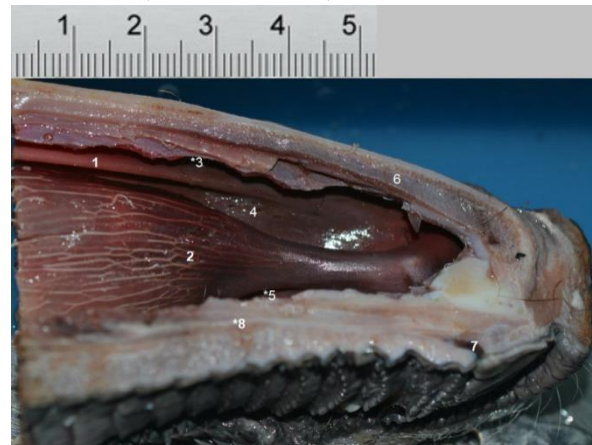


Figure 9; Sagittal section of the rostral part of the nasal cavity, medial view of the left side.1: Dorsal nasal concha; 2: Ventral concha with superficial blood vessels; 3: Dorsal meatus; 4: Middle meatus; 5: Ventral meatus; 6: Nasal septum; 7: Incisive duct; 8: Vomer nasal organ.



Figure 10; Sagittal section of the rostral part of the nasal cavity, medial view of the right side. 1: Dorsal nasal concha; 2: Ventral nasal concha; 3: Middle meatus; 4: Ventral meatus; 5: Hard palate; 6: Incisive duct; 7: Vomeronasal organ.

The dorsal concha was simple (Figures 1, 2, 4, 5, 6), had a dorsal turbinate sinus and was attached caudally to the lamina papyracea of the ethmoid and extended rostrally into a cartilaginous part called rectus fold.

The ventral concha, also called maxilloturbinate (Figures 1, 2, 3, 4, 5, 6, 8), was inserted over the conchal crest of the maxillary bone and was more developed than its dorsal counterpart. It had a double curl, a main lamina fixed to the maxilla that was divided into dorsal and ventral laminae (Figures 1, 2, 5, 6, 8). The caudal limb of the ventral lamina was simple and did not form a ventral conchal sinus. This turbinate was continued with two cartilaginous extensions, the alar and basal folds.

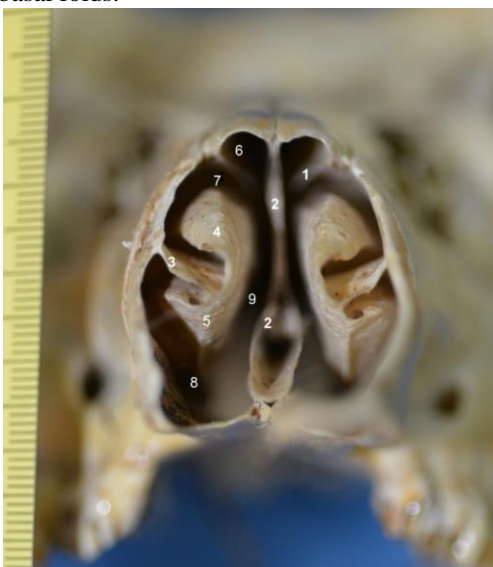


Figure 1; Rostral view of the skull (nasal cavity) of the pampas deer. 1: Dorsal nasal concha; 2: Nasal septum; 3: Main lamina of the ventral concha; 4: Dorsal lamina of the ventral concha; 5: Ventral lamina of the ventral concha; 6: Dorsal meatus; 7: Middle meatus; 8: Ventral meatus; 9: Common meatus.

The middle nasal concha was the first and largest volute of the ethmoid or endoturbinated (Figures 2, 3, 4). There were no mucous folds associated with this turbinate. The ethmoid turbinates (Figures 2, 4, 7) that formed the ethmoidal labyrinth were formed by the scrolls of the ethmoid and covered by olfactory mucosa. The scrolls of the ethmoid or ethmoturbinated (Ethmoturbinalia) were divided into two groups, the ectoturbinados and the endoturbinates. The endoturbinates were only visible in the sagittal section of the head that passed near the septum, to which the middle turbinate belonged. The ethmoid turbinates were separated by the narrow ethmoid meatus (Figure 7) that were the spaces between them. These were finished caudally in a cul-de-sac against the lamina cribrosa of the ethmoid.

There were on each side of the nasal cavity four nasal passages or meatus: dorsal nasal meatus, middle nasal meatus, ventral nasal meatus and common nasal meatus. These meatus were presented as longitudinal depressions between the conchae (Figures 1, 2, 3, 4, 8).

The relatively narrow dorsal nasal meatus (Figures 1, 9, 10) ran through the dorsal nasal concha and terminated caudally on the cribriform plate of the ethmoid. Its roof was formed by the nasal bone in its rostral section and the frontal in the caudal part. The dorsal nasal meatus was regularly in open communication with the common nasal meatus.

The narrow middle nasal meatus (Figures 1, 4, 9, 10) was situated between the dorsal and ventral nasal conchae. The dorsal spiral lamina of the ventral concha and the spiral lamina of the dorsal concha were partially overlapped and narrowed the middle nasal meatus. The middle nasal meatus was divided caudally into a dorsal and ventral part by the middle nasal concha. The ventral part of the middle nasal meatus was continued towards the nasopharynx in the ventral part of the ethmoidal labyrinth, ventrally to which the ventral nasal concha ended.

The spacious ventral nasal meatus (Figures 1, 3, 4, 8, 9,

10) was delimited dorsally by the alar fold and the basal lamina of the ventral nasal concha. The floor of the nasal cavity formed its ventral termination. The ventral nasal meatus flowed caudally to the nasopharynx.

The common nasal meatus (Figures 1, 8), formed between the roof of the nasal cavity and the floor of the nasal cavity, on the one hand, and between the nasal septum and the nasal conchae, on the other hand, had its greatest width at the level of the ventral spiral lamina of the ventral nasal concha.

The vomeronasal organ of the pampas deer was located ventrally on the floor of the nasal cavity, laterally to the surface of the nasal septum (Figures 9, 10). The organ itself was contained in an envelope of cartilage (Cartilagovomeronasale) that extends from approximately the rostral part of the palatine bone to the incisive canal. The organ communicated with the oral cavity through the incisive canal, finally opening on each side of the incisive papilla (Figures 17, 18).

The paranasal sinuses found in the pampas deer were the frontal, maxillary, palatine and lacrimal (Figures 9, 10). They were small and poorly developed. It is necessary to consider that these sinuses communicated with the nasal cavity and there were sinuses in the dorsal and middle nasal conchae, but not in the ventral one.

The larynx of *Ozotoceros bezoarticus* was located cranially in the neck ventrally to the first two cervical vertebrae, suspended to the hyoid bone and joined to the pharynx and beginning of the esophagus (Figures 11, 12, 15). Considered as a whole, the larynx was elongated in cranio - caudal direction, wider dorsally than ventrally where the laryngeal prominence ended up protruding.

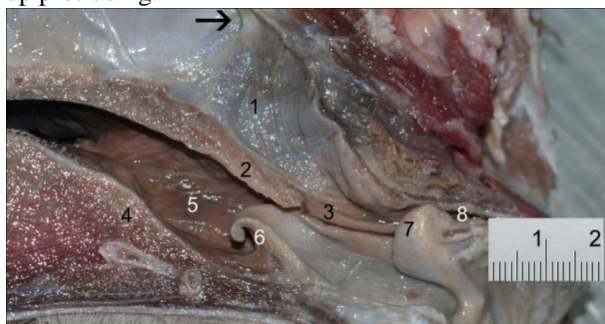


Figure 11. Medial view of the right half of the pharynx and larynx of the pampas deer after median section of the head. 1: Nasopharynx; 2: Soft palate; 3: Palatopharyngeal

arch; 4: Root of the tongue; 5: Oropharynx; 6: Epiglottis; 7: Corniculated process of the arytenoid cartilage; 8: Esophagus



Figure 15; Left ventrolateral view of the neck region. 1: Sternobasilar portion of the sternocephalic muscle; 2: Sternomandibular portion of the sternocephalic muscle; 3: Sternothyroid muscle; 4: Cricothyroid muscle; 5: Thyrothyoid muscle; 6: Laryngeal prominence.

The total length of the larynx was 52.76 ± 7.66 mm from the epiglottis to the caudal edge of the cricoid cartilage. The dorsoventral length was 30.32 ± 3.71 mm (Figures 13, 14).

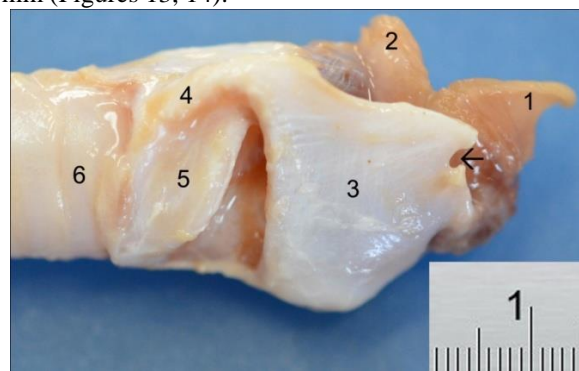


Figure 13; Right side view of the larynx of the female pampas deer. The muscles, vessels and nerves were removed. 1: Epiglottis; 2: Corniculated process of the arytenoid cartilage; 3: Thyroid cartilage; 4: Caudal horn of the thyroid cartilage; 5: Cricoid cartilage; 6: Trachea. →: Thyroid fissure.

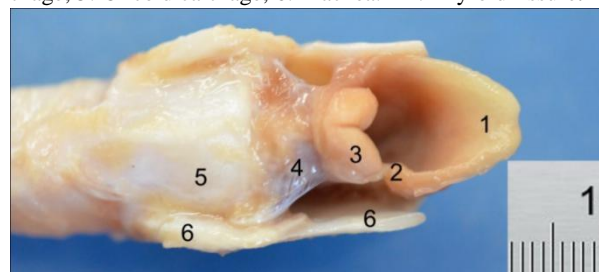


Figure 14; Dorsal view of the larynx of the female pampas deer. 1: Epiglottis; 2: Ariepiglotic fold; 3: Corniculated process of the arytenoid cartilage; 4: Transverse arytenoid muscle; 5: Cricoid cartilage; 6: Thyroid cartilage.

The larynx was formed by three unpair cartilages:

the cricoid, the thyroid and the epiglottis, and an even cartilage: the arytenoid. There were no accessory cartilages. The thyroid, cricoids and arytenoid cartilages without the corniculated processes were of hyaline cartilage, while the epiglottis and the corniculated processes of the arytenoids were of elastic cartilage.

The largest cartilage of the larynx was the thyroid, odd and symmetrical, consisted in two convex and irregular laminae fused in the midline (Figures 4, 5, 6). The thyroid cartilage was cranial to the cricoid cartilage, caudal to the epiglottis and laterally to the arytenoid cartilages (Figures 12, 13, 14, 15). Both side plates of the thyroid cartilage were smooth laterally, formed a large part of the lateral wall of the larynx and at their median junction formed the laryngeal prominence, which was undeveloped and tuber-shaped (Prominentialaryngea) (Figures 12, 15). This prominence was equally prominent in both sexes.

It was related dorsally to the base of the epiglottic cartilage, which adhered to the laryngeal prominence by the tiroepiglottic ligament, which was elastic, thick and strong. There was a rostral horn in the thyroid cartilage and a thyroid fissure, where the cranial laryngeal nerve entered, which was distributed to the mucosa of the organ (Figure 13). The caudal horn was very long (Figure 13).

The cricoid cartilage had typically the form of a signet ring and was rostral to the first tracheal cartilaginous ring and caudodorsally to the thyroid cartilages (Figures 13, 14). The cricoid cartilage had caudally articular surfaces for the thyroid, and articular surfaces in the rostral part of the lamina to the arytenoid cartilage. The caudal edge of the cricoid was thin and was joined to the first tracheal ring by the cricotracheal ligament. The internal surface was very soft and covered by the respiratory mucosa.

The arytenoid cartilages were irregular with pyramidal shape and were located rostrally to the cricoid cartilage and a little dorsally to the thyroid cartilages (Figures 11, 13, 14). The corniculated processes of the arytenoid cartilage (Figures 11, 13, 14) were formed by elastic cartilage and the rest of the cartilage was hyaline.

The epiglottis cartilage had an elongated leaf shape and was located cranially and medially to the

thyroid cartilages (Figures 11, 13, 14). The lingual surface of the epiglottis was concave from the apex to the base while the laryngeal surface was very elongated and planiform. There were no cuneiform cartilages. In all the animals studied, the epiglottis was located ventrally to the soft palate, which was visualized in the medium cuts made in the corpses (Figure 11).

The cartilages of the larynx were joined together and to the hyoid bone by two types of joints, synovium and syndesmosis. The synovial joints were the cricothyroid and the cricoarytenoid joints. The cricothyroid joint joined the corresponding lateral facet of the cricoid cartilage to the caudal horn of the thyroid cartilage and the synovium was reduced. The cricothyroid ligament extended between the cricothyroid joints closing ventrolaterally the space between the cricoid and thyroid cartilages. The arytenoid cartilages are joined together by a small transverse arytenoid ligament, which is covered dorsally by the small transverse arytenoid muscle. The cricoarytenoid joint is very small and synovial. The union of the arytenoids to the thyroid is given by the vocal fold. Finally, the base of the epiglottis was attached to the thyroid by a thyroepiglottic ligament.

The larynx was attached to the hyoid bone at the thyrohyoid joint, which links the thyrohyoid to the rostral horn of the thyroid cartilage. This joint is fibrous, without a synovium. The cricotracheal ligament joined the thyroid cartilage to the first ring of the trachea, was broad and elastic.

The extrinsic muscles of the larynx were poorly developed and represented by the thyrohyoid, sternothyroid and hyoepiglottic muscles (Figure 15). There was no sternohyoid muscle. The width of the thyrohyoid muscle in its middle part was 9.69 ± 1.37 mm. The width of the sternothyroid muscle in the vicinity of its termination on the thyroid cartilage was 9.85 ± 1.33 mm. The hyoepiglottic muscle was very small. The intrinsic muscles of the larynx were: cricothyroid, dorsal cricoarytenoid, lateral cricoarytenoid, transverse arytenoid, and thyroarytenoid. The lateral cricoarytenoid was hidden by the laminae of the thyroid cartilage and were very little developed.

The Adituslaryngis was 25.98 ± 9.5 mm long and 11.1 ± 3.09 mm wide, and its edge was formed ceane-

overtrally by the epiglottis, laterally by the ariepiglottic folds and dorsocaudally by the corniculated process of the arytenoid cartilage (Figures 11, 14). The thickness of the ariepiglottic folds was 1.93 ± 0.93 mm. The thickness of the corniculated processes of the arytenoid cartilage was 4.46 ± 0.9 mm.

The laryngopharynx or laryngeal part of the pharynx extended between the base of the epiglottis and the beginning of the esophagus, ventrally to the intrapharyngeal ostium. Between the epiglotticvallecula (Valleculaepiglottica) and the beginning of the esophagus, two deep grooves, the piriform recesses, were extended (Figure 15).

The laryngeal cavity was connected rostrally with the laryngopharynx and caudally with the tracheal cavity (Figures. 11, 13). Three parts, the vestibule or supraglottic part, the glottis and the infraglottic part formed this cavity. There was a median depression in the floor of the vestibule of the larynx, rostral to the union of the vocal folds: the medial recess of the larynx (Recessuslaryngismedianus). 10). The glottis, a narrow central part of the laryngeal cavity, had the usual two parts, intercartilaginous dorsal between the arytenoid cartilages and ventral intermembranous between the vocal folds (Plica vocalis), forming a central rhombic structure. The length of the vocal fold was 14.8 ± 3.25 and its width was 3.84 ± 0.46 mm.

The supraglottic part is wider, limited rostroventrally by the epiglottis, dorsocaudally by the arytenoid cartilages and laterally by the ariepiglottic folds.

The length of the infraglottic part of the larynx was 16.01 ± 2.77 mm. It was broad and short, with no caudal demarcation, composed mainly of the cricoid cartilage and the cricothyroid ligament.

Unlike the nasopharynx and oropharynx, there were no tonsils in the laryngopharynx, or paraepiglottic tonsils (Tonsillaparaepiglottica).

The caudal part of the laryngopharynx that gave rise to the esophagus corresponded to the esophagus vestibule (Vestibulumoesophagi) and was located in front of the cricoid cartilage. The ventral part of the laryngopharynx was occupied by the long entrance of the larynx (Adituslaryngis).

The irrigation of the larynx and its muscles was mainly given by two direct branches of the common

carotid artery, the cranial and caudal laryngeal arteries. The veins were mostly satellites.

The cranial and caudal laryngeal nerves, branches of the X cranial nerve or vagus nerve, gave the innervation of the larynx. The cranial laryngeal nerve had only one internal branch that was distributed to the mucosa of the organ and entered through the cranial thyroid incisura. The recurrent laryngeal nerve proceeded from the thorax and accompanied the trachea dorsolaterally, and when it reached the larynx with the name of caudal laryngeal nerve it was distributed mainly to the intrinsic muscles.

4. Discussion

According to our knowledge, this is the first whole anatomical description of the nasal cavity and larynx in a deer species. This is particularly important for pampas deer considering the conservation status of this species. One limitation for vets and surgeons of zoo animals and wildlife is the scarce information available on the anatomy of these species, increasing the risks during any treatment due to possible inadequate approaches. Therefore, having available basic anatomical knowledge of anatomy is very important for different applications.

The nasal cavity of mammals is an intricate anatomical structure with a variety of shapes, sizes and functional roles. The "fundamental conformation" of the nasal cavity remains relatively consistent in most mammals (Moore, 1981) and in fact the same happens in the pampas deer. The nasal conchae help to present an irregular and winding route for air flow during inhalation. As the inspired air travels through the airways, the increased surface area (partly thanks to the turbinates arrangement) fulfills multiple functions such as air conditioning, filtration of contaminants, smell and conservation of heat and water (Negus, 1958; Schmidt-Nielsen *et al.*, 1970; Moore, 1981).

The most rostral portion of the nasal cavity, the nasal vestibule is the main responsible for the filtration and transport of inspired air to the respiratory region. Due to the lack of appreciable vasculature, very little conditioning of the inspired air occurs in the nasal vestibule, which is lined with squamous epithelium (Craven *et al.*, 2007, Harkema *et al.*, 2006, Negus, 1958, Reznik, 1990). Continuing, the air flows caudally

through the respiratory region of the nasal cavity, where the conchae extend from the lateral walls.

Conchae complexity tends to vary depending on the lifestyle and functional needs of the species (Van Valkenburgh *et al.*, 2011), with the more complex arrangement typically found in Ungulates and Carnivores (Negus, 1958, Van Valkenburgh *et al.*, 2014). The increasing order of complexity in turbinates includes: simple winding, double winding and branching (Negus, 1958, Craven and others, 2007, Van Valkenburgh *et al.*, 2014). For the case of pampasdeer we have a simple winding for the dorsal turbinate and a double winding for the ventral turbinate. This is the same as found in domestic ruminants (Barone, 2010)

The maxilloturbinate or ventral concha of white-tailed deer is approximately 50% of the total length of the nasal cavity (Ranslow *et al.*, 2014), like in pampas deer. Although the deers had a much simple ventral concha than in the carnivores, the structure is extended by a greater distance in order to increase the surface area. The length of a concha can compensate for the lack of complexity as seen with the extended, but simple, double spiral winding of these deer species.

In the olfactory region, etmoturbed complexes also present a large surface area to increase the deposition of odoriferous substances that come with the air flow. Etmoturbinets play the main role in smell (Craven *et al.*, 2010). These turbinates are present in varying degrees in most adult mammals, with the exception of some cetaceans in which olfactory structures are reduced or lost (Berta *et al.*, 2014).

In animals with high olfactory capacity (macrostatic) (eg, rodents, carnivores, ungulates), the dorsal meatus directly connects the olfactory region with the nasal vestibule, providing a way for the airflow to elude the respiratory region during inspiration (Craven *et al.*, 2007, Craven *et al.*, 2010; Lawson *et al.*, 2012; Ranslow *et al.*, 2014).

Ranslow *et al.* (2014) showed that the white-tailed deer has simple ventral turbinates, but very complex etmoturbinates compared to carnivores. The white-tailed deer has bent moths that are more intricate than those of other animal moths, which, as observed by Ranslow *et al.* (2014), provides a larger surface for smelling in a compact space.

The vomeronasal organ is a very important structure and in the pampas deer it communicates directly with the oral cavity by the incisive canal. The vomeronasal organ was described in detail in the sheep by Kratzing (1971). It is reported that flehmen occur much more frequently in deer during the mating season than in other occasions (Muller-Schwarze, 1979). This organ is used as a final determinant for the recognition of offspring during lactation in sheep (Booth, 2006). Even in sheep, sexual dimorphism has been described in this organ, being somewhat larger in males (Khosravinia and Abbasi, 2014). It is necessary make physiological studies of this organ in pampas deer.

In mammals, the great diversity of habitats and social systems has led to the evolution of a great variety of vocal tract specializations. Some studies (Bisailon, 1985, Frey and Gebler, 2003, Frey *et al.*, 2006, Frey *et al.*, 2007a, b) have been carried out to date showing that the anatomical and physiological aspects of the larynx in the wild animals. These studies have demonstrated functional characteristics and explanations of the mechanisms of vocalization (Harrison, 1980, Frey and Gebler, 2003, Frey *et al.*, 2006; Frey *et al.*, 2007a, b) and the taste buds of the larynx (Bradley *et al.*, 1980; Yamamoto *et al.*, 2001).

The larynx of pampas deer was located cranially in the neck, ventrally to the first 2 cervical vertebrae. This location varies with the degree of flexion and extension of the neck in the different species, its caudal edge reaches the fourth cervical vertebra in the pig, in equines it is found in the intermandibular space (Barone, 2010). The descending larynx has been used to differentiate the human from other animal species where the larynx is closer to the oral cavity (Fitch and Reby, 2001). The descending larynx has been described in the Mongolian gazelle (Frey and Gebler, 2003), in the red deer stag (*Cervuselaphus*) and in the male stag deer (Damadama) (Fitch and Reby, 2001). In these species the larynx can be retracted during vocalization which lengthens the vocal tract and allows the roar that the males emit.

It is composed of the same cartilages as domestic ruminants, lacking cuneiform cartilages. In contrast to many ruminants, it was reported that the width of the laminae of the thyroid cartilage was greater than its

length, acquiring a triangular shape (in the camel of a hump (Saber, 1983)). The caudal horn of the thyroid cartilage was 2.5 times longer than the rostral horn in musk ox (Frey *et al.*, 2006), and the rostral horn was relatively smaller in the reindeer (Frey *et al.*, 2007a). As in *Ozotoceros*, the rostradorsal angle of the lamina was extended to form the short straight rostral horn and the thyroid fissure was a deep notch between the rostral horn and the rostral edge of the thyroid lamina in the cow and sheep (Getty, 1975) and the white-tailed deer (Bisaillon, 1985). Through this fissure the cranial laryngeal nerve in these species and in *Ozotoceros* entered into the larynx. The caudal horn was similar to that of domestic ruminants (Getty, 1975), musk ox (Frey *et al.*, 2006) and reindeer (Frey *et al.*, 2007a). In the white-tailed deer (Bisaillon, 1985), the caudal horn was shorter, but thicker than its rostral counterpart. The laryngeal prominence is underdeveloped just like domestic ruminants.

Cricoid cartilage is the typical signet ring in many domestic and wild mammals (Getty, 1975, Hast, 1979, Bisaillon, 1985, Frey *et al.*, 2006, Frey *et al.*, 2007a, b, Barone, 2010). In *Ozotoceros*, the same form of cricoid cartilage was observed. It was not indented in its lower part like the ox. The rostral edge of the lamina had the same thickness as the caudal margin, on the contrary of the Ox and the white-tailed deer where the rostral edge is wider (Basaillon, 1985).

The epiglottic cartilage was shaped like an elongated leaf in *Ozotoceros*. Likewise, it has the shape of a vaulted leaf on the sheep and the ox, and like a cordate leaf on the goat (Barone, 2010). Like white-tailed deer and ruminants, the ariepiglottic fold is strong and fuses with its counterpart on the dorsal surface of the arytenoid cartilages.

On the other hand, there was no cuneiform cartilage of the epiglottis in *Ozotoceros*. Likewise, the absence of cuneiform cartilages, caudally directed and located on both sides of the epiglottis, was reported in the cat, sheep, goat and cattle (Getty, 1975, Hast, 1979, Guinard, 2005, Barone, 2010). On the other hand, the cuneiform cartilage is present in the dog, the horse (Getty, 1975, Niquel, 1987) and the Mongolian gazelle (Frey and Gebler, 2003).

The arytenoid cartilages were similar to those of

the sheep (Getty, 1975, Goulden, 2002, Barone, 2010). The corniculated processes were joined by their base to the apex of the arytenoid and curved cartilages dorsally and medially curved in ruminants and horse, as in *Ozotoceros* (Barone, 2010).

Ozotoceros was devoid of a ventricle of the larynx. This ventricle is present in horses, pigs, dogs and to a lesser extent in the rabbit (Barone, 2010). In its place there is only a weak depression in domestic ruminants (Barone, 2010). The laryngeal ventricle is homologous to the exit air larynx (*Saccuslaryngis*) of the primates that descends caudally in the neck, even to the axillary region in the orangutan (Hayama, 1970).

The anatomy of the larynx and vocalization was studied in the musk ox (Frey *et al.* 2006). This species forms harems and access to females is given by spectacular agonist encounters between males with the association of a very marked male roar during periods of heat. The roar in adult females is given more for communication with the child. This species presents a marked sexual dimorphism in the anatomy of the head, but not in the larynx, where the region of the glottis is thicker in the male. They are provided with an ventro-rostral odd ventricle in the larynx that is inflated with air during the initial phase of the roar, which can give more amplitude and a serious timbre to the roar acting as a resonance chamber. *Ozotoceros bezoarticus* had no laryngeal ventricle similar to that described in the musk ox.

In the saiga antelope (*Saigatatarica*) the nose is involved in vocal production, producing nasal grunts (Frey *et al.*, 2007b). This animal also fights for the possession of 5 to 50 females. Also have been described particularities in the vocal folds of this species (Frey *et al.*, 2007b).

The Mongolian gazelle (*Procapragutturosa*) also has a lowered larynx, a wide epiglottis, a great development of the laryngeal muscles and the presence of highly developed laryngeal ventricles (Frey and Gebler, 2003). In this species the competition between males for reproduction is vigorous.

The reindeer and the caribou (which are of the same species: *Rangifer tarandus*) that have polygamous mating system, a male creates a group of 20 to 100 females with fighting between males (Frey *et al.*,

2007a). These animals are characterized by characteristic vocalizations called grunts in the males that also occur in the female to communicate with the child. The vocal tract of the reindeer has evolved to a peculiar specialization, the laryngeal air sac, being the only species described of cervid to possess it (Frey *et al.*, 2007a). This structure that emerges from the laryngeal vestibule increases the amplitude of vocalization according to these authors.

In animals that have a mating system by harem, few males have the majority of females, therefore the vocalization helped by the laryngeal sac can reduce the number of fights between males by acoustic rejection and by attraction of the females, being very advantageous (Frey *et al.*, 2007a).

Therefore, the mating system seems to be related to snarling or growling-type vocalizations, being more noticeable in polygamous species that form harems, a situation contrary to what happens in *Ozotoceros bezoarticus* (Ungerfeld *et al.*, 2008b). The joints and muscles of the larynx of *Ozotoceros bezoarticus* were similar to those of domestic ruminants. Regarding the innervation of the organ, the main difference found was that the cranial laryngeal nerve did not emit a branch for the cricothyroid muscle, which does happen in domestic ruminants (Barone, 2010).

We need detailed histological examinations of the distribution of the olfactory epithelium versus non-sensory epithelium within the nose. These data are essential to understand the function of the turbinates and the nasal cavity in general. In the same way detailed studies of the physiology of the vomeronasal organ and larynx (especially related to vocalization) are necessary.

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