An anatomical study of the dorsal and ventral nasal conchal bullae in normal horses: Computed tomographic anatomical and morphometric findings

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Summary

Reasons for performing the study: Infection of the dorsal nasal conchal bulla (DCB) and ventral nasal conchal bulla (VCB) has recently been shown to cause clinical disease in horses, but the anatomy of these two structures is poorly documented.

Objectives: To describe the anatomical features, dimensions and relationships to adjacent structures of the DCB and VCB in normal horses using computed tomography (CT).

Study design: *Ex vivo* imaging study

Methods: Computed tomographic images acquired from 60 equine cadaver heads that were shown to be free of sino-nasal disease were categorised into three age groups (0-5; 6-15; >16 years of age). Linear and volumetric measurements and descriptive anatomical assessments of the DCB and VCB were produced from these CT images and the anatomical relationships between the DCB and VCB and the adjacent structures, particularly the maxillary cheek teeth, were examined. The associations between bullae dimensions with horse ages and skull dimensions were assessed using linear regression.

Results: Mean DCB measurements were: length 7.5cm (4.6-14), width 1.9cm (1.25-2.5), height 2.8cm (1.8-4), volume 24cm^3 (5.9-50.5). Mean VCB measurements were: length 5.7cm (2.5-8.5), width 1.6cm (0.7-2.9), height 2.4cm (0.8-3.7), volume 15cm^3 (0.4-30). There were significant differences in size of both DCB and VCB between the different age groups (smaller in younger animals), which in the case of the VCB, was likely related to protrusion of the large dental alveoli of younger horses into the lateral nasal cavity. Measures of bullae size and volume were significantly associated with head size. The anatomical positions (rostro-caudal boundaries) of the DCB and VCB were closely associated with specific maxillary cheek teeth

Conclusions: Computed tomography was a useful technique to establish the linear and volumetric dimensions of the nasal conchal bullae in normal horses. Both DCB and VCB sizes increased with animal age. Relatively consistent anatomical relationships were shown between the rostral and caudal limits of the bullae and certain maxillary cheek teeth, which would be of diagnostic value with conventional radiography and act as landmarks in the surgical treatment of nasal bulla disease.

Keywords: horse, nasal conchal bulla, ventral conchal bulla, dorsal conchal bulla, anatomy, computed tomography

Introduction

The standard nasal conchal (turbinate) pattern in domestic animals is of a large dorsal and ventral conchae attached to the lateral aspect of the nasal cavity, with a smaller middle conchus lying between them [1]. The equine dorsal and ventral nasal conchae are relatively simple in shape compared to many other species. Both are comprised of a single scroll of mucosa-covered, thin bone, with the dorsal concha scrolled ventrally and the ventral concha scrolled dorsally, without any of the complex, secondary conchal scrolls that are present in many other domestic species [1, 2, 3, 4,].

The dorsal and ventral equine nasal conchae each contain an air filled bulla, which have been respectively termed the *scrolled portion of the dorsal turbinate* and *the large bulla of the middle portion of the ventral turbinat*e by Sisson and Grossman [5]; and more recently and correctly as the B*ulla conchalis dorsalis* and *Bulla conchalis ventralis* [1,6]. Espersen (1952) published line diagrams of these nasal bullae [7]. Confusingly, the thin, bulbous, dorsal aspect of the maxillary septum has also frequently been termed the *Ventral conchal bulla*, [8] however it has recently been recommended that this structure is more appropriately termed the maxillary septal bulla (*Bulla of the septum sinuum maxillarium*) [7, 9].

Diseases of the paranasal sinuses are the most common cause of unilateral nasal discharge in horses [10, 11]. It has recently been reported that empyema of the DCB or the VCB, can occur concurrently with paranasal sinusitis, exacerbating the clinical signs and less commonly as a sole disorder [9]. Despite the clinical importance of the nasal conchal bullae, their anatomy remains poorly described, particularly in the English language literature.

The advent of computed tomography (CT) has permitted much more accurate imaging of the complex equine sino-nasal region, including allowing detailed anatomical studies of the paranasal sinuses to be performed [3,4,9,12,13]. Additionally, the ability to perform CT imaging in standing sedated horses has resulted in improved acceptance by owners, facilitating its increased clinical use.

A companion study [14] has examined the gross anatomical and histological features of these nasal bullae in normal horses. The aim of this study is to describe the anatomy of the DCB and VCB using CT, focusing on their linear and volumetric dimensions, and age-related changes in these parameters, as well as the anatomical relationships of the bullae to adjacent maxillary cheek teeth.

Material and methods

Specimens

Heads were available from two sources:

Group A: The heads of 28 horses with unknown histories were collected from an abattoir (Scottish rendering facility). These grossly appeared similar in size to Thoroughbred horse heads.

Group B: Anatomical and CT images of a further 32 equine heads that had also been obtained from an abattoir were kindly donated by Justine Perkins (JP) of the Royal Veterinary College in London.

Age of animals in both groups was estimated by clinical and/or imaging dental examinations of heads, which were then categorised into one of three age groups: 0-5 years old (n= 13); 6-15 years old (n=21); > 16 years old (n=26).

Imaging Protocols

Computed tomographic images of the 28 Group A heads were acquired with a multislice scanner (Siemens Volume Zoom) using a 512x512 Matrix, 120 Kv, 300 mA, at a slice thickness of 1.5 mm, with the skulls positioned on their mandibles. Transverse CT images of the head were acquired in a helical scan mode. The CT images were examined by imaging and surgical Diplomates for the presence of sinonasal disease or significant dental abnormalities including the following: apical changes, presence of gas within dental pulps and apices, dental dysplasia, supernumerary teeth, apical fractures, sinus mucosal thickening, abnormal sinus content, and frontal, nasal or maxillary bone changes. Suspect lesions were subsequently directly examined following transverse or longitudinal sectioning of the skulls using a band saw. Thirty heads which showed sino-nasal or any of the above dental abnormalities were excluded from the study.

The CT images of the 32 horses in Group B were acquired using a 4^{th} Generation, Universal Medical System CT scanner, GE light speed ultras at 1.25mm slice thickness, 120Kv, 300 mA. Only bone windows were available for review. These heads were examined by an experienced equine surgeon Perkins (JP) who had considered them free of sino-nasal or significant dental abnormalities.

Image manipulation

Bone window CT data were available for review in all 60 heads. The CT data were transferred as DICOM images to imaging software (Osirix, Apple®) [15] which was used to perform multiplanar reconstructions of images to allow identification and descriptions of the DCB and VCB and to perform all measurements.

Measurements

Bullae linear dimensions:

Using Osirix® software, linear measurements were made for each DCB and VCB including: maximum length, height and width. Dorsal reconstructions of images (Fig 1A and B) were used for measurements of bullae lengths and widths, while sagittal reconstructions (Fig 2 A and B) were used to measure bullae heights. Means and ranges were produced for each linear measurement.

Bullae volumes

The volume of each bulla was calculated using three dimensional regions of interest (3D ROIs)/Volume (Osirix® software) in two ways:

1. *Total slice protocol:* the internal boundary of each bulla was outlined on *transverse* images using every image slice (with a 1.5mm slice thickness n=28 horses; 1.25mm slice thickness n=32 horses) resulting in a mean of 60 slices per bulla.
2. *Limited slice protocol:* To reduce the time taken, the internal boundary of each bulla was outlined on *transverse* images using just 4 or 5 slices per bulla.

Head linear dimensions and volumes:

"Head length" was measured from CT sagittal reconstruction from the caudal aspect of the orbit to the naso-incisive notch. "Head width" was measured from CT dorsal reconstruction across the width of the hard palate at Triadan 06 level and "Head height" was measured using CT sagittal reconstruction from the hard palate to the dorsal aspect of the maxillary bone, also at Triadan 06 level. These three measurements were multiplied together to produce a measurement of “head volume” for each horse.

Assessment of rostral and caudal anatomical limits of bullae in relation to adjacent cheek teeth

In order to describe the anatomical relationships of the bullae to the adjacent maxillary cheek, the rostral and caudal bony limits of each bulla were identified in multiplanar dorsal image reconstructions. The maxillary cheek teeth were subdivided into 5 equal sections rostro-caudally and labelled with odd numbers to facilitate graphing, as shown in Figure 3. Transverse lines (z-axis) were drawn from the most rostral and caudal bullae margins and the maxillary tooth and section transected were recorded. A summary of the most rostral and caudal measures from each horse were then plotted, subdivided by age group (Fig 3).

Comparison of head dimensions with those of 12 horses of known breed

To allow comparison of the head sizes in the study population with the head sizes of known breed, computed tomographic studies of 12 Thoroughbreds of known age (4= 0-5 years old; 4= 6-15 years old; 4= >16 years old) that had undergone CT head imaging for clinical reasons other than sinonasal disorders were collected. “Head” length, width and height were measured and “head” volume was calculated.

Statistical Analysis

Paired T-tests were used to examine for statistically significant differences in length, height, width and volume between left and right DCB and VCB; and between the two methods used to calculate conchal bullae volumes.

Correlation matrices were calculated and linear regression was used to examine the relationships between bullae sizes and "head" sizes for each of: length, height, width and volume.

Linear regression was used to evaluate the relationship between bullae volumes and age groups.

To examine how the head sizes (length, width, height, volume) of the study population compared with the head sizes of 12 known Thoroughbred breeds, box and whisker plots of head sizes, subdivided by age were produced. Linear regression was used to evaluate whether measures of head size differed significantly between the study population and the known Thoroughbred population. To account for the effect of age, "age group" was included as an explanatory variable in the linear regression models.

Results

Descriptive Morphology

In all cases, the DCB and VCB were completely enclosed by a thin bony wall, surrounded by circa 300° of nasal conchae scrolled ventrally for the DCB and dorsally for the VCB. The dorsal aspect of the DCB and the ventral aspect of the VCB had bony and soft tissue attachments to the inner aspects of the nasal conchae that in turn were supported by the bony conchal attachments to the lateral nasal walls. In all heads a scroll of bone-free nasal conchae overlapped the medial aspect of the conchal bullae, but never fully overlapped their lateral aspects. In particular, the ventromedial aspect of the DCB and the dorsomedial aspect of the VCB (both in the middle meatus) were not covered by nasal concha. The DCB lumen was characterised by the presence of multiple, vertical, thin, soft-tissue septae, which transversely divided it into several Cellulae, with the VCB containing fewer such septae (Fig 4A). The nasal drainage of bullae could not be detected on CT images due to the small size of the drainage apertures and because of the surrounding soft tissue structures. Many of the horses in the youngest age group had significant lateral compression of their VCBs (Fig 4B). The left VCB in one case had an abnormally shrunken appearance when compared to the contralateral side and other heads, and therefore this case was excluded from further analyses.

Bullae linear dimensions

Mean and ranges of linear dimensions for each DCB and VCB are presented in Table 1. The DCB was of larger dimensions than the VCB.

There were no significant differences between the left and right sided bullae measurements in individual horses. Consequently all further analyses were performed using the mean of the left and right side measurements.

Bullae volumes

There were significant differences in DCB and VCB volume measurements between the two measuring protocols ($P=<0.001$, $P<0.001$, respectively), with the *Limited slice protocol* underestimating the bullae volumes, compared to the *total slice protocol* (Table 1). Consequently, all subsequent volume analyses were made using the total image slice protocol.

There was no statistical difference between the volumes of the left and right DCB or VCB in individual horses ($P=0.5796$, $P=0.8267$). Consequently all further analyses were performed using the mean of the left and right side volume measurements.

Associations with head size

All parameters of sizes and volume were significantly associated between bullae and heads. Results of correlation matrices and linear regressions between bullae and head sizes are shown in Table 2.

Associations with age

Results of linear regression between bullae volumes and age groups are shown in Figure 5. The volumes of both the DCB and the VCB differed significantly between age groups (model P-values = 0.005 and 0.0005, respectively) with age group 0-5 years having significantly smaller volumes (mean DCB volume 15.6cm^3 [5.9-35.1]; mean VCB volume 8.5cm^3 [0.4-21.5]) than the >16 years age group (mean DCB volume 24.7cm^3 [10.1-41.2]; mean VCB volume 17.2cm^3 [4.6-26.2]). It appeared that the difference in size with age for the VCB was due in part to the intra-nasal protrusion of the larger alveoli of maxillary cheek teeth in younger horses (Fig.4B).

Comparison with heads of known size

Box plots showing ranges of head sizes in the study group and known Thoroughbred group, subdivided by age groups are shown in Figure 6. Heads in the study group were significantly smaller than the known Thoroughbred group with smaller "head": lengths (mean length 17.3cm compared to 18.1cm, P=0.043), heights (mean height 9.5cm compared to 11.1cm, P<0.001) and volumes (mean volume 1123cm^3 compared to 1358cm^3, P=0.005), but no significant difference was present in widths (mean width 6.6cm compared to 6.8cm, P=0.185).

Anatomical relations of bullae to adjacent cheek teeth

DCB

The rostral limit of the DCB was parallel with the maxillary Triadan 07s in 48/59 (81.3%) of horses, parallel with the 06s in 10/59 (17%) cases and parallel with the 08s in 1/59 (1.7%)

case. The caudal limit of the DCB was found to lie parallel with the maxillary Triadan 10s in 36/59 (61%), the 09s in 18/59 (30.5%), the 11s in 3/59 (5%) and the 08s in 2/59 (3.5%).

VCB

The rostral limit of the VCB was parallel with the maxillary Triadan 07s in 46/59 (78%) of horses, parallel with the 06s in 11/59 (19%) cases and parallel with the 08s in 2/59 (3%) cases. The caudal limit of the VCB was found to lie parallel with the maxillary Triadan, the 09s in 38/59 (64.5%), and the 08s in 19/59 (32%) and the 10s in 2/59 (3.5%).
The relations between both DCB and VCB and sections of the adjacent maxillary teeth are shown in Figure 3

Discussion

This study describes CT anatomical features and linear and volumetric dimensions of the equine DCB and VCB, structures that are now recognised to suffer significant clinical disease [9], but whose anatomy remains poorly described. Computed tomography allows evaluation of single image slices in different scanning planes and the use of specialised software additionally allows accurate linear and volumetric measurements to be obtained.

Some excellent CT anatomical studies of normal equine head structures, including sinuses and teeth have recently been described [3, 4, 16,17]. However, minimal imaging information has been reported on the anatomy of normal or diseased nasal conchal bullae. Morphometric cranial measurements using CT have been described in dogs [18, 19] and more recently, volumetric measurements of normal equine paranasal sinuses were calculated using three-dimensional reformatted rendering of CT slices, using commercial software (Amira™) [4]. This technique was shown to be of value in demonstrating the complex three-dimensional anatomical structures of the paranasal sinuses. However that commercial software is expensive and it takes between 8-12 hours of work to calculate the sinus volumes for a single head [4], making this technique impractical for routine diagnostic work.

In contrast, calculating nasal conchal bullae volumes using the current software (Osirix®) [15] was much quicker (1.5hour/head), required minimal training and no software purchase. Osirix volume calculation necessitates the manual outlining of the inner border of each CT image slice for each bulla, making it prone to human error, due to the undulating inner surface of the conchal bulla. This undulating surface might explain the observed significantly lower bullae volumes calculated from the limited slice protocol as compared to the complete slice protocol.

Transverse CT images consistently showed free scrolled nasal conchae overlying most of the surface of the bullae, including the most accessible medial aspects of both bullae that prevent direct trans-nasal surgical access to the conchal bulla, unless the vascular nasal concha is penetrated first. Consequently, surgical drainage of infected bullae generally requires an approach through the middle meatus [9], where both bullae are not covered by the free nasal conchae. The presence of asymmetrical shrinkage of the left VCB in one case was of unknown cause, but considered potentially related to previous disease of this bulla or congenital malformation and as such this case was excluded from analysis. The observed lack of significant difference in DCB and VCB volume and size measurements between left and right sides was expected. While asymmetry in horses that had previous pathology or surgery in the area of the bullae might be expected, an inclusion criteria of this study was that the population were free of sino-nasal disease.

"Head" volumes and bullae volumes were found to be significantly associated irrespective of age. Head volume was calculated from the width and the height of the maxillary bone at the maxillary Triadan 06; and the distance between the caudal aspect of the orbital bone to the naso-incisive notch, because these parameters were measurable in all specimens. Although measurement from the occipital bone to the incisive bone would have provided a measurement more closely associated with full skull length, the measurements used were thought acceptable for the analyses in this paper, whose aim was to measure bullae sizes.

Considerable ranges in bullae linear and volumetric measurements were observed, and this variation was most marked in the VCB (Table 1). Horses in the youngest age group had significantly smaller DCBs and VCBs than those in the oldest age group. Many of the horses in the youngest age group had significant lateral compression of their VCBs (Fig 4B) due to intrusion of the alveoli of young maxillary cheek teeth apices into the nasal passages. Although, previously recognised [20], this feature has not previously been related to VCB compression. The reason for the significant difference in size of the DCB between youngest and oldest age groups is thought likely to be related to changes in overall head size as the animal grows. The lack of the significance when comparing the middle age group is likely related to reduction in growth rate after the age of 5 years.

A limitation of this study was the absence of breed information for the examined heads. Comparison of head linear and volume parameters with 12 adult Thoroughbred horses indicated the study cases were significantly (circa 10%) smaller than those of adult Thoroughbreds and this should be taken into account when considering the normal range of bullae sizes in horses.

Another limitation of this study was that it was performed on cadaver heads and thus the normal venous distension of some areas of the nasal mucosa was absent and this venous distension would likely have decreased the volumes of the DCB and VCB.

The rostral and caudal limits of the DCB were found to be parallel with the maxillary Triadan 06s and 11s, respectively in some cases, thus showing that the caudal limits of the DCB is adjacent to the rostral limits of the dorsal conchal sinuses, however, no overlap between the DCB and dorsal conchal sinus was found in any head. It is commonly stated that the apices and reserve crowns of the caudal 3-4 cheek teeth (Triadan 08s-11s) lie within the rostral and caudal maxillary sinuses [21,22]. However, there is much variation between horses in these anatomical relationships; with the rostral aspect of the rostral maxillary sinus reported as varying from being level with the Triadan 07 to 09 cheek teeth, and the maxillary septum varying in site from being level with the caudal aspect of the Triadan 08 to the caudal aspect of the Triadan 09 [23-24]. In this study population, the rostral and caudal borders of the VCB extended from the level of the Triadan 06s to the 10s, respectively in some cases, thus showing that the caudal limits of the VCB can overlap with the rostral limits of the ventral conchal and rostral maxillary sinuses. In the presence of concurrent sinusitis and DCB or VCB empyema, the boundaries between these structures may not be obvious using conventional radiography, but the anatomical relationships between the rostral and caudal limits of these bullae and the adjacent maxillary cheek teeth gives useful anatomical guidelines for diagnosis of bulla empyema on conventional radiography and also landmarks for the trans-nasal surgical treatment of such disorders.

Conclusions

Computed tomography was a suitable technique to establish the linear dimensions and volumes of the nasal conchal bullae in horses of different ages. Both DCB and VCB sizes increased with animal age, the latter in part due to the eruption of cheek teeth whose reserve crowns were compressing the bulla. Relatively consistent relationships between the rostral and caudal limits of these bullae and the adjacent maxillary cheek teeth were observed, that would be of diagnostic value with conventional radiography and also in the surgical treatment of sino-nasal disease.

Manufacturer details

Multislice CT scanner Siemens Volume Zoom, Munich, Germany

4th Generation, Universal Medical System CT scanner, GE light speed ultras, Highland Heights, Ohio, USA

Statistical software: Stata (version 12)

Tables:

Table 1: Mean dorsal conchal bulla and ventral conchal bulla measurements for 59 horses in study, subdivided by “head” side. (TSP=total slice protocol; LSP=limited slice protocol)

	Left	Right	Mean Left & Right
Dorsal conchal bulla			
Mean Length (Range) [cm]	7.48 (4.4-14)	7.5 (4.7-14)	7.49 (4.55-14)
Mean Width (Range) [cm]	1.86 (1.3-2.4)	1.88 (1.2-2.6)	1.87 (1.25-2.5)
Mean Height (Range) [cm]	2.8 (1.8-4)	2.74 (1.8-4.1)	2.77 (1.8-4.05)
TSP Mean volume (Range) [cm^3]	23.83 (5.5-49)	24.12 (6-53)	23.98 (5.85-50.45)
LSP Mean volume (Range) [cm^3]	22.54 (5.1-46.1)	22.77 (4.3-51)	22.66 (4.9-48.55)
Ventral conchal bulla			
Mean Length (Range) [cm]	5.68 (2.4-8.4)	5.67 (2.5-8.5)	5.68 (2.45-8.45)
Mean Width (Range) [cm]	1.62 (0.5-2.9)	1.64 (0.7-2.8)	1.63 (0.7-2.85)
Mean Height (Range) [cm]	2.39 (0.8-3.6)	2.41 (0.8-3.7)	2.4 (0.8-3.65)
TSP Mean volume (Range) [cm^3]	15.13 (0.2-31)	15.01 (0.5-29)	15.07 (0.35-30)
LSP Mean volume (Range) [cm^3]	14.42 (0.2-30)	14.35 (0.5-27.9)	14.39 (0.35-28.95)

Table 2: Results of linear regression and correlation matrix comparisons between individual measures of head sizes and measures of bullae sizes. Horse is included as a random effect to account for clustering. Significant associations are highlighted with bolded P-values.

Head / Bullae comparison	Linear Regression Coefficient	95% C.I.	Std. Err.	P-value	Correlation Coefficient
DCB					
Length (cm)	0.475	0.22-0.73	0.13	**<0.001**	0.4253
Width (cm)	0.884	0.15-1.6	0.38	**0.019**	0.2919
Height (cm)	0.708	0.13-1.28	0.29	**0.016**	0.2990
Volume (cm^3)	16.89	9.02-24.77	4.02	**<0.001**	0.4801
VCB					
Length (cm)	0.51	0.15-0.88	0.19	**0.006**	0.3360
Width (cm)	1.05	0.56-1.54	0.25	**<0.001**	0.4809
Height (cm)	0.84	0.38-1.29	0.23	**<0.001**	0.4226
Volume (cm^3)	24.25	13.2-35.3	5.62	**<0.001**	0.4894

Key: DCB=dorsal conchal bulla; VCB=ventral conchal bulla.

Figures

<u>Fig 1 (A-B)</u>

Dorsal multiplanar reconstruction of a cadaver equine head. Key: L= Left; R= Right; white arrow showing sites of measurement of the length and width of the Ventral Conchal Bulla (VCB)(A) , and Dorsal Conchal Bulla (DCB) (B)

<u>Fig 2 (A-B)</u>

Sagittal multiplanar reconstruction of a cadaver equine head. Key: D = Dorsal; R = Rostral; V = Ventral, showing sites of measurement of the height of the left VCB (A) and left DCB (B)

<u>Fig 3</u>

Diagram showing maxillary cheek teeth sections and Box plots showing most rostral and caudal extents of the dorsal and ventral conchal bullae, subdivided by age groups. DCB=Dorsal conchal bulla; VCB=Ventral conchal bulla; Tooth level refers to the level transected: whole number refers to the Triadan number while decimal place refers to the section as depicted in Figure 5.

Fig 4 (A-B)

A:Ventral multiplanar reconstruction of a cadaver equine head at the level of 08 maxillary cheek tooth. (L; Left; R: Right). Note white arrows indicating septae formation within the DCB and VCB

B: Transverse image of a cadaver equine head < 4 years old, (L= Left; R= Right). Note the small size of the left and right ventral conchal bullae (arrows) due to protrusion of the tall reserve crowns of the erupting 07 maxillary cheek teeth.

<u>Fig. 5</u>

Box plots showing ranges of mean volumes of the dorsal (DCB) and ventral conchal bullae (VCB), subdivided by age groups.

<u>Fig. 6</u>

Box plots showing comparison of head sizes in the study group (x-axis=SG) with known Thoroughbred group (x-axis=Tb), subdivided by age groups. Lower and upper box lines=25th and 75th percentiles, respectively; Middle box line in bold=median; lower and upper whiskers =lower and upper adjacent values, respectively; open circles=outliers.

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