Anatomic Reference for Computed Tomography of Paranasal Sinuses and Their Communication in the Egyptian Buffalo (Bubalus bubalis)

M. A. M. Alsafy, S. A. A. El-Gendy and A. A. El Sharaby

Addresses of authors: 1 Department of Anatomy & Embryology, Faculty of Veterinary Medicine, Alexandria University, Alexandria, Egypt; 2 Department of Anatomy & Embryology, Faculty of Veterinary Medicine, Damanhour University, Damanhour, Egypt

*Correspondence:
Tel.: +2 016 4191 119;
fax: +2 045 3591 017;
e-mail: elsharaby@yahoo.com

With 12 figures

Received December 2011; accepted for publication August 2012
doi: 10.1111/ahe.12005

Summary

The purpose of this work was to present an anatomic reference for computed tomography (CT) for the paranasal sinuses of adult buffalo fit the use of anatomists, radiologists, clinicians and veterinary students. CT images with the most closely corresponding cross sections of the head were selected and studied serially in a rostral to caudal progression from the level of the interdental space to the level of the nuchal line. The anatomical features were compared with the dissected heads and skulls. The paranasal sinuses of buffalo comprise dorsal conchal, middle conchal, maxillary, frontal, palatine, sphenoidal (inconstant, small and shallow when present), lacrimal and ethmoidal that were identified and labelled according to the premolar and molar teeth as landmarks. The topographic description of all the compartments, diverticula, septa and communication of the paranasal sinuses in buffalo has been presented. The relationship between the various air cavities and paranasal sinuses was easily visualized.

Introduction

The buffalo (Bubalus bubalis) and domestic cattle (Bos taurus) are part of the bovine family and subfamily, but from there branch out into different tribes and genus and are indeed quite different critters. The buffalo population in the world is actually about 168 million head: 161 million can be found in Asia (95.83%); 3717 million are in Africa, almost entirely in Egypt (2.24%); 3.3 million (1.96%) in South America; 40 000 in Australia (0.02%); 500 000 in Europe (0.30%). It is employed as a draught animal, but also produces meat, horns, skin and particularly the rich and precious milk that gives creams, butter, yoghurt and many cheeses, including the delicious mozzarella (Borghese, 2005). Paranasal sinuses are paired cavities within the skull and develop by evagination of the nasal mucosa into the spongy bone between external and internal plates of cranial and facial bones. Thus, each sinus is lined by respiratory epithelium and has a direct opening to the nasal cavity except for the lacrimal and palatine sinuses, which are diverticula of maxillary sinus (Nickel et al., 1986; Budras et al., 2003). Many of the clinically important septa of paranasal sinuses in ruminants are not solid and completed by membranes that do not survive maceration (Konig and Liebich, 2007; Shojaj et al., 2008). Understanding of the position and extent of the paranasal sinuses, their communication with each other, associated structures and nasal cavity is important in interpretation of the diseases of the upper respiratory passages and the disorders of adjacent structures (Losonsky et al., 1997; Morrow et al., 2000; Reetz et al., 2006). Infectious and non-infectious inflammatory disease, trauma, dental and nasopharyngeal diseases can cause clinical signs localized to the nasal cavity and paranasal sinuses (Barrington and Tuckerd, 1996; Reetz et al., 2006). To our knowledge, few publications are available on the anatomy of the paranasal sinuses in the buffalo (Moustafa and Kamel, 1971; Saigal and Khatra, 1977; Kumar and Dhingra, 1980). Yet, a vague understanding is still unexplained for the complexities of these sinuses in buffalo, that is, their extension, location, their contribution to the teeth and their communications with the nasal cavity and horns.
Computed tomography (CT) has become an accepted alternative imaging modality to assess the head region that far surpasses what can be provided by survey radiography (Solano and Brawer, 2004). In addition, CT is more accurate in the diagnosis of location, extension and characterization of the nasal cavity lesions and its usage is improving in the detection of large animal's disorders, especially in the head region (Gerros et al., 1998; Vink-Nooteboom et al., 1998; Saunders and Van Bree, 2003). Unlike other areas of the body, the head of several animals could be fully scanned and produced detailed cross-sectional images of the nasal cavity and paranasal sinuses without superimposition of other anatomical structures in several animals: equines (Morrow et al., 2000; Kraft and Gavin, 2001; Tucker and Farrell, 2001; Smallwood et al., 2002; Solano and Brawer, 2004; Probst et al., 2005; De Zani et al., 2010; El-Gendi and Alsafy, 2010); dog (Burk, 1992; George and Smallwood, 1992; De Rycke et al., 2003); cat (Losonsky et al., 1997; Koch et al., 2002; Reetz et al., 2006); and goat (Barrington and Tuckerd, 1996; Arencibia et al., 1997; Shojaei et al., 2008). It is noteworthy that we found only one article, which has mentioned the CT on the head of large ruminant (camel: Zhong et al., 2008). The purpose of this report is to provide an atlas of normal cross-sectional anatomy of paranasal sinuses and their communication in the buffalo using CT images and transverse sections to fit the use of anatomists, radiologists, surgeons and veterinary students.

Materials and Methods

Collection and preparation of materials

The heads of five healthy adult male buffalo weighting 500–550 kg with 7–8 years of age were collected from the slaughterhouse. The heads were removed from the level of the third cervical vertebra. Two heads were kept frozen for the subsequent CT imaging and cross-sectional anatomy. In the remaining heads, the external carotid artery was injected first by warm saline, and then, the heads were fixed by 10% formalin injection. In addition, three skulls of adult animals were carefully macerated in accordance with the method described by Onar et al. (1997).

Topography of the paranasal sinuses

Three skulls and three cadaver heads were used to study the anatomy of paranasal sinuses and their communication after removing the overlying frontal, maxillary, lacrimal, nasal bones from two skull and cadaver heads by electric saw. Sagittal sections were performed on one cadaver head and one skull.

CT scans

The CT examination was applied on the freshly collected buffalo head, which was serially sectioned using the CT scanner (CT-W450-10A, HITACHI, Japan). The scanned images were taken rostrally from the tip of nostrils caudalwards until the level just caudal to the nuchal line where the used slice thickness was 1.5 cm with 2-cm CT scan intervals (scanning conditions: 130 KV, 100 MA)

Cross sections

Two frozen buffalo heads were serially cut using a table of band saw, and the cross sections were approximately 2 cm apart beginning from the level of the nostrils until the level caudal to the nuchal line. The slices were numbered and gently cleaned from debris with water and light brushing and were photographed immediately with the caudal surface of each slice facing the camera. We used the neck of the premolar and molar teeth as landmarks to explore and describe the location and extension of the structures and cavities. They have been previously employed for this purpose because of their constant position in the hard palate and their easily recognition within the images of cross sections (Probst et al., 2005 and Shojaei et al., 2008). For documentation, the images were printed as hard copies and stored digitally for offline investigation.

Results

Computed tomography scans obtained excellent bone window images of the fine bone and soft tissue architecture of the paranasal sinuses and nasal cavity. The relationship between various air cavities was easily visualized. CT images (Figs 1–9a–a) with the most closely corresponding cross sections of the buffalo head (Figs 1–9b–b) were selected. These images belong to one buffalo head that has been selected and subsequently serially cut. They are presented in a rostral to caudal progression from the level of the interdental space to the level of the nuchal line. The paranasal sinuses of buffalo comprised the dorsal conchal, middle conchal, maxillary, frontal, palatine, sphenoidal, lacrimal and ethmoidal that were identified and labelled according to the cheek teeth as landmarks.

Dorsal conchal sinus

The dorsal conchal sinus was located in the caudal part of the dorsal nasal concha and appeared clearly at the level of the 3rd premolar to the 3rd molar teeth (Figs 10/12; 4/2). It was communicated with the rostral frontal sinus by
The nasofrontal opening, which was situated in the caudal part of the sinus. Thus, it was communicated indirectly with the nasal cavity through the frontal sinus (Fig. 10c/16).

The middle conchal sinus
The middle conchal sinus was located in the middle nasal concha, extended ventral to the dorsal conchal sinus rostrally from the cribriform plate to the level of the 3rd molar teeth (Fig. 10/13), and opened into the ethmoidal meatus.

The ventral conchal sinus was absent, as the caudal part of the ventral nasal concha was occupied by the spiral nasal concha (Figs 10/4; 1–6/3). The conchal sinuses have low-density thin wall, while the dorsal and ventral nasal conchae have medium-density thick wall.
and spiral form (Figs 1a; 2a; 5a/2, 3). The nasal septum reached the floor of the nasal cavity where the vomeronasal organ appeared as a pair of ducts on each side of the nasal septum and supported by a thin cartilage extended from the incisive duct at the level of the 4th incisor tooth to the level of the 2nd premolar tooth (Figs 1–3/9).

The frontal sinuses were very extensive within the frontal and parietal bones rostrodorsal to the brain and extended well into the cornual process of the frontal bone. The sinus cavity appeared irregular rectangular in shape and
was subdivided into numbers of cavities by numerous partitions that were variable in sizes and positions between animals and from right to left sinus (Fig. 11). The left and right frontal sinuses were separated by a complete median interfrontal septum (Figs 11/8; 8/11; 9/4). The frontal sinus extended rostrally to the level of the middle of the 3rd molar tooth. This was estimated by a line at the level of rostral half of orbital rim, which was represented by nasofrontal suture in the macerated skull. The caudal boundary of the sinus was the nuchal line of occipital bone. The sinus extended laterally to about 2 cm medial to the orbital rim and temporal line (Fig. 11b). The frontal suture together with the interfrontal septum and the midline marked the medial limits of the sinus. In CT scans, the frontal sinus contained high-density septa and bony plates (Figs 6/16; 7/13; 8/8, 9, 10). The cavity of the frontal sinus was divided into rostral and caudal sinuses by an oblique transverse septum (Fig. 11b/12). The rostral sinus was subdivided by two irregular oblique longitudinal and transverse septa (Fig. 11b/13) into several small lateral (Figs 11b,c/16; 8a,b/10), medial (Figs 11b,c/14; 8A-B/8) and intermediate (Figs 11b,c/15; 8a,b/9) compartments. All rostral sinus compartments communicated separately with the ethmoidal meatus and rostrally with the dorsal nasal sinus by nasofrontal opening (Fig. 10c/16). A part of the dorsal nasal concha projected caudally between the medial and intermediate rostral sinuses and the lateral rostral sinus was separated by a thin septum from the lacrimal sinus (Fig. 11b/19). The caudal sinus was subdivided by an incomplete oblique transverse septum into large caudolateral (Figs 11/17; 8c,d/14) and small rostromedial (Figs 11/18; 8c, d/15) sinuses, which were communicated with each other. The caudal sinus was subdivided by oblique frontal transverse septum into two subcompartments, of which the most caudolateral part was separated from nuchal diverticulum by another oblique transverse septum. The cavity of caudalateral sinus contained three diverticula: the nuchal, cornual and postorbital diverticula. The nuchal diverticulum was more extensive because of well-developed parietal bone and was further subdivided into four subcompartments (Figs 11b,c/9; 9/5). The cornual diverticulum extended into the cornual process of frontal bone (Figs 11/10; 9/6) and subdivided by a septum (Fig. 11b/20). While the postorbital diverticulum located medial and caudal to the orbit and dorsal to the cranial cavity, occupying the space between the orbital cavity and rostral frontal small compartments (Fig. 11/11). The supraorbital canal was short and passed through the lateral border of the caudal frontal sinus through an apparently bony septum (Fig. 11/7). The caudal frontal sinus opened at its rostral end to the ethmoidal meatus. The cranial cavity bulged into the central part of the frontal sinus.

The maxillary sinus

The maxillary sinus was excavated in the maxillary and lacrimal bones (Figs 12/4, 3–7/12). The sinus cavity was triangular in shape with its base directed caudally and the
apex cranially behind the infraorbital foramen. The cavity extended rostrally to the facial tuberosity (Fig. 12b–d/4) at the level of the caudal border of the 2nd premolar tooth (Fig. 12/P2). About 2–3 cm ventral to the orbit and caudal to 3rd molar tooth (Fig. 12/M3), the sinus continued caudally into the thin-walled lacrimal bulla (Fig. 7/12) and zygomatic bone. The dorsal limit of the cavity was determined by a line extending from the infraorbital foramen to the medial canthus of eye, while the ventral limit was 1–2 cm above the alveolar border. In CT scans, the infraorbital canal and bony spicules of the maxillary sinus showed visibly higher density (Figs 3–7/12).

The maxillary sinus was communicated with the caudal part of middle nasal meatus in common with the palatine sinuses through nasomaxillary opening (Figs 12c/7; 10d/17). This opening (Fig. 6a,b,d/19) was located on the medial wall just ventral to the nasolacrimal canal (Figs 12b/9; 5/18; 6/14), over the infraorbital canal (Figs 12c/8; 3/13) and midway between the orbit and facial tuber at a level from the 1st molar to 3rd molar teeth. The maxillary sinus was also communicated with the palatine sinus through an oval maxillopalatine opening that is situated above the infraorbital opening at a level from 2nd premolar to the 2nd molar teeth (Figs 12b/6; 5,6/9). Caudally, it was also communicated with

the lacrimal sinus through maxillolacrimal opening. There was a rostral crest within the maxillary sinus (Figs 5a,b/19, 6a,b/15).

The lacrimal sinus

The lacrimal sinuses had low density in CT and bounded by high-density thick wall. It was a small excavation in the lacrimal and frontal bones rostromedial to the orbit (Figs 12b/5; 8/16), its lateral wall was formed by lacrimal bone, while the medial wall was formed by lateral mass of the ethmoidal bone. The sinus cavity was not divided by osseous plates and the nasolacrimal canal traversed its lateral wall. It was communicated with the maxillary sinus by maxillolacrimal opening.

The palatine sinus

The palatine sinus was located within the horizontal part of the palatine bone and the palatine process of maxillary bone (Figs 10a–d/15; 1–7/10) and appeared larger than the maxillary sinus. The right and left palatine sinuses were separated by a median interpalatine septum (Figs 10b/25; 1–7/11), which was undulant caudally. The sinus extended from the caudal border of the palatine bone and rostral border of orbit about 2 cm caudal to the 3rd molar tooth (Fig. 7/10) to about 3–4 cm rostral to the 1st premolar teeth (Fig. 1/10). The sinus cavity was subdivided into two unequal compartments by an incomplete transverse bony crest arose from the floor of sinus (Figs 12d/17; 10c,d/30). The caudal part of the sinus was traversed obliquely by the infraorbital canal (Fig. 10c,d/26) that was divided it into medial and lateral compartments (Fig. 10c,d/28, 29). The palatine sinus was communicated with the maxillary sinus by maxillopalatine opening over the infraorbital canal. The palatine sinus appeared in the CT with low density and had high-density structures; infraorbital canal in the caudal part, undulant interpalatine septum and palatine canal (Figs 3/13; 6/11, 18).

The sphenoidal sinus

The sphenoid sinus was shallow excavated in the body and wing of the sphenoid bone (Fig. 10b/23). The right and left sinuses were divided by a septum into unequal small parts; rostral canal and caudal cavity. It was noticeable small and shallow only in two specimens. It opened into the ethmoidal meatus by nasosphenoidal opening.

The ethmoidal cells

The ethmoidal cells were small cavities in the medial wall of the orbit (Fig. 12d/19). Their medial walls were formed by the ethmoid bone, while their lateral walls were formed by the frontal, palatine and the wing of presphenoid bones. The ethmoidal cells opened into the ethmoidal meatus.
Discussion

In the present study, CT provided excellent spatial resolution and good discrimination between the bone and soft tissue of the buffalo head, and the paranasal sinuses and adjoining cavities have more differential appearance within the CT slices. We used the cheek teeth neck as landmarks because of their constant position in the hard palate and because of their easily recognition within the cross-sectional images. They have been employed for this purpose in equines Probst et al. (2005) and Shojaei et al. (2008). Our observations on the maxillary, frontal, palate, sphenoidal, lacrimal and ethmoidal sinuses in addition to the dorsal and middle conchal sinuses coincide greatly with the findings of Moustafa and Kamel (1971) and Kumar and Dhingra (1980) and are not greatly variable than those in the other bovines (Nickel et al., 1986).

We recorded that the nasal septum reaches the floor of nasal cavity with the presence of vomeronasal organ on each side of the nasal septum. This seems a peculiar feature in the buffalo as compared to the cattle where the septum fails caudally to reach the floor of nasal cavity.
forming a single median channel that continues the paired nasal passages into the nasopharynx (Dyce et al., 2002). We also found the dorsal conchal sinus occupying the caudal part of dorsal nasal concha, and the middle conchal sinus occupied the middle concha, while the ventral conchal sinus was absent because of the presence of spiral lamellae within the caudal end of ventral nasal concha. This is in agreement with Moustafa and Kamel (1971) and similar to the cattle as mentioned by Gadzhev (1980). However, it contrasts the mention of Nickel et al. (1986) that it exists in the upper region of ox bounded by the two limbs of basal lamella, spiral lamellae and a thin lateral
plate. We demonstrated that the sphenoidal sinus appeared small and shallow only in two specimens in gross anatomy and not identified on both, CT and cross section; this result was in line with that recorded by Moustafa and Kamel (1971) and Saigal and Khatra (1977) stated that it was not noticeable.

Similar to other bovines (Nickel et al., 1986; Budras et al., 2003), we observed that the frontal sinuses in buffalo are divided into numerous interconnected diverticula by ridges and partial septae, and the cornual diverticulum to extend into the frontal sinus. This coincides with the findings of Saigal and Khatra (1977) and Kumar and Dhingra (1980) and seems an adaptation for shock absorption and protection of the brain and other cranial structures from the impact force during fighting (Schaffer and Reed, 1972; Frake, 2008). In agreement with Moustafa

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and Kamel (1971) and Kumar and Dhingra (1980), the left and right frontal sinuses were separated completely by interfrontal septum. Meanwhile in cattle, El-Hagri (1967) found a communication between the two frontal sinuses caudally where the interfrontal septum was deficient. We demonstrated an extensive nuchal diverticulum that might be apparently because of the well-developed parietal bone. It is further subdivided into four subcompartments, which is agreement with the findings of Saigal and Khatra (1977), Kumar and Dhingra (1980). We found also the caudolateral part of frontal sinus, that is, cornual diverticulum, extended within the cornual process, this extension of cor-nual diverticulum inside the horn core varied greatly from animal to another, and the extension is not related to sex, age or size of the animal, which was also reported by Moustafa and Kamel (1971), Saigal and Khatra (1977). Kumar and Dhingra (1980) added that it is and the nuchal diverticulum are absent in the buffalo calf. In agreement with Kumar and Dhingra (1980), we found a short supraorbital canal, which passes through the lateral border of the caudal frontal sinus through a complete plate of bone. In addition, we found the rostral frontal sinus subdivided into numerous small lateral, medial and intermediate compartments, which in contrast with the mention of Nickel et al. (1986) in cattle that the intermediate compartments are inconsistent.

In the present study, all the openings and communications of the paranasal sinuses were clearly observed in the CT and cross and sagittal sections of the buffalo head. These observations are in agreement with the findings of Moustafa and Kamel (1971); Saigal and Khatra (1977); Kumar and Dhingra (1980), and mostly similar to those in other bovines (Nickel et al., 1986; Budras et al., 2003). The nasomaxillary opening was situated on the medial wall midway between the orbit and facial tuber at a level from 1st molar to 3rd molar teeth. This location is relatively high and might hinder the natural drainage of the pus or other fluids from the maxillary sinus as stated by Dyce et al. (2002). According to Saigal and Khatra (1977), the nasomaxillary opening is not distinguishable because of its continuity with the defect in the roof of palate sinus, whereas in ox, it is the opening that is much narrower and lies dorsal to the opening of the maxilopalatine, and in small ruminants, it lies in dorsal passage of the middle conchal meatus caudally (Nickel et al., 1986). We observed the rostral frontal compartments to communicate with dorsal nasal sinus by naso-frontal opening, which is in agreement with the observation by Moustafa and Kamel (1971) who added that it is partially closed in the fresh state by a thin layer of mucous membrane. This is in contrast to Kumar and Dhingra (1980) who found one or two openings at the level of the second molar tooth and Saigal and Khatra (1977) who reported 5–6 foramina in the floor of the rostrolateral frontoal sinus. In contrast to Kumar and Dhingra (1980), we found the caudal compartment of the frontal sinus to communicate rostrally at its floor with the ethmoidal meatus, which was also reported in bovines (Nickel et al., 1986; Budras et al., 2003).

Finally, our findings support the mention of Saigal and Khatra (1977)that the most suitable site of trephining the maxillary sinus could be located at about the midpoint between the infraorbital margin and the facial tuber. They also added that the most suitable trephining site of frontal sinus is on a line joining the middles of temporal regions about midway between the median plane and the lateral margin of the head. However, we found that the cranial cavity bulged into the central part of the frontal sinus. This should be considered if trephining will be carried out through a line across the rostral margin of the orbits and medial to the frontal vein, which ascended on the frontal bone to the supraorbital foramen that was just behind the plane of the lateral canthus of eye.

We conclude that CT and cross-sectional anatomy are important to clarify the basic and characteristic features of the paranasal sinuses and their communications with the adjoining cavities in the buffalo head as compared to other ruminants.

References


