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ORIGINAL ARTICLE

Anatomic Reference of Nasal Cavity and Paranasal Sinuses in the Wild Goat (*Capra aegagrus*) Using Computed Tomography

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CT Anatomy of Paranasal Sinuses in Wild Goat

Abstract

The wild goat (*Capra aegagrus*) is a Near Threatened species and a key progenitor of the domestic goat. Despite its conservation value, anatomical knowledge of its craniofacial features is still restricted. Although computed tomography (CT) is widely used in veterinary medicine, there is a notable gap in the literature regarding the detailed sinus structures of *C. aegagrus*. The purpose of this study was to employ CT to document the normal morphology of the paranasal sinuses in *C. aegagrus*, establishing a species-specific anatomical baseline. Four clinically healthy adult wild goats were put under general anesthesia and subjected to CT imaging using a helical CT scanner. Transverse images with a slice thickness of 1 mm were acquired and assessed in both soft tissue and bone windows. CT images were matched to cross-sections of two domestic goats to confirm identification of the sinuses. The frontal, maxillary, palatine, lacrimal, and conchal sinuses were inspected for size, shape, and position. All principal paranasal sinuses were identified in *Capra aegagrus*. The frontal sinus was the largest, occupying a significant part of the cranial vault. The palatine sinus was well-developed and connected to the maxillary sinus by a clearly defined opening, whereas the maxillary sinus was clearly separated into distinct lateral and medial compartments. Despite its small size, the lacrimal sinus was consistently identified in all specimens. Along with the nasal turbinates, the conchal sinuses were clearly visible. These findings resembled those of domestic goats; however, wild goats had a more consistent and pronounced palatine sinus. This study presents a detailed CT-based atlas of paranasal sinus anatomy in *Capra aegagrus*, serving as an essential reference for veterinary diagnostics, surgery, and conservation medicine. Further studies utilizing 3D reconstruction and larger sample sizes will augment anatomical and clinical comprehension.

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Introduction

Capra aegagrus, or wild goat, belongs to the family Bovidae, subfamily Caprinae, and is recognized as the direct wild progenitor of the domestic goat (*Capra hircus*), having played a central role in early livestock domestication in the Near East. This medium-sized herbivore is evolutionarily and ecologically adapted to high-altitude environments and rugged, mountainous ground, on which it has the impressive agility and climbing ability to outmaneuver predators such as leopards, cheetahs, and wolves. *Capra aegagrus* has a patchy and fragmented distribution from the Mediterranean mountain ranges of eastern Turkey and northern Iran through the dry mountain ranges of Pakistan and Afghanistan to the dry, mountainous regions of India, Iran, Iraq, and Turkmenistan (1-3). High ecological dependence upon rocky substrates and mountainous slopes underscores its specialization for habitat and vulnerability to human-made pressure. Populations of *Capra aegagrus* have undergone severe declines over their native range due to a variety of anthropogenic factors, including overharvest, illegal hunting, competition with domestic stock, and further destruction and decline of their habitats. These are threats that have led to fragmented populations with a marked decline in numbers, leading conservation authorities to consider the species as globally threatened. The International Union for Conservation of Nature (IUCN) currently lists *C. aegagrus* as Near Threatened from their most recent assessments (2016/2020), with over 30% decline in some populations (1, 2, 4, 5). Wild goat plays a significant ecological role in the determination of the composition and structure of the rangelands and plant community of mountain ecosystems. Despite widespread investigations of their complete scope of ecosystem influences having been constrained, wild goats are known to compete with domestic livestock for forage resources, potentially influencing pasture dynamics and rangeland quality. Moreover, *C. aegagrus* serves as an important prey species for large carnivores such as leopards, wolves, and cheetahs, and hence contributes towards the stabilization and resistance of the trophic networks in their native habitats. With its evolutionary value as the ancestor of the domestic goat and its ecological function in mountain ecosystems, the conservation status of the species highlights the essential value of comprehensive research on its anatomy, physiology, and health towards the development of efficient conservation and management actions (2).

In artiodactyls such as goats and sheep, the sinuses are especially elaborate, often extending far into the frontal (horn) cores, maxillae, and other skull bones. The air cells have several functions. Anatomically, they reduce the weight of the skull and enlarge the nasal airway, enhancing olfaction. Functionally, sinuses are hypothesized to dampen mechanical forces, regulate cranial temperature, and even resonate vocalizations. Indeed, the large frontal sinus in horned ruminants appears closely linked to the size of the frontal bone and horn core, suggesting a structural role in absorbing impact stresses. Histological and imaging studies further note that sinus septa and bony struts increase the attachment surface for muscles and vasculature. Mammalian paranasal sinuses are pneumatic (air- filled) chambers within the cranial bones that communicate with the nasal cavity. These sinuses form a complex, species-specific system of chambers – in goats, typically including the frontal, maxillary, lacrimal, palatine, and conchal sinuses – with roles in respiratory physiology, cranial biomechanics, and potentially thermoregulation (6-9).

Detailed knowledge of sinus anatomy is critical in veterinary practice. Conventional radiography is often inadequate for intricate sinus morphology, whereas cross-sectional imaging, particularly computed tomography (CT), provides unparalleled detail of bone and soft tissue interfaces. In small animals and livestock, CT has become the gold standard for sinus evaluation (10-12). For example, equine studies using 3D CT reconstructions have quantified sinus volumes and revealed fine anatomy of all seven sinus compartments, directly informing the diagnosis of equine sinusitis and surgical planning (13-15). Clinically, CT greatly enhances the detection of sinonasal disease in veterinary patients (16). In dogs with chronic nasal discharge, CT imaging consistently revealed the extent of turbinate destruction and masses, allowing differentiation between neoplasia and inflammatory rhinitis and guiding biopsies (11, 17). CT-based anatomical mapping has recently been applied to other wild ruminants, further emphasizing the need for species-specific datasets (18). Thus, CT provides detailed cross- sectional anatomy and pathological insight that are invaluable for diagnosis and intervention in sinonasal disorders.

Despite extensive imaging data on domestic goats and sheep (19-23), *Capra aegagrus* has received little tomographic study. Comprehensive CT mapping of *C. aegagrus* sinuses is necessary for both basic and applied reasons. First, it will fill a gap in comparative anatomy by documenting the similarities and differences between the sinuses of wild goats and those of domestic goats. Second, as an at- risk species, detailed knowledge of normal sinus anatomy is crucial for veterinarians managing health or injuries in captive or free- ranging wild goats (6). CT imaging of a live *C. aegagrus* skull will establish normative morphometry and the pattern of sinus communications, forming a baseline for detecting pathological changes. In summary, the tomographic anatomy of wild goat paranasal sinuses is justified by both scientific interests in caprine craniofacial evolution and the practical needs of wildlife medicine and conservation.

Materials and Methods

Animals

Four adult wild goats (*Capra aegagrus*; two males and two females) were used in this study. The animals were clinically healthy, aged between 2 and 4 years, and weighed 20-45 kg. They were fasted for 12 hours prior to imaging.

Anesthesia and Positioning

Premedication was achieved by intramuscular injection of atropine sulfate (Daroopakhsh, Iran) at a dosage of 0.04 mg/kg to reduce the salivary and bronchial secretions. General anesthesia was induced with intravenous ketamine hydrochloride (Alfasan, The Netherlands) at 2.2 mg/kg combined with xylazine hydrochloride (Alfasan, The Netherlands) at 0.11 mg/kg. Each goat was then positioned in sternal recumbency to optimize head alignment with the imaging plane. The head was placed so that the X-ray beam was perpendicular to the plane of the hard palate, ensuring consistent and anatomically correct transverse sections.

CT Imaging Protocol

CT images were acquired using a third-generation helical CT scanner (Toshiba Xvision EX, Japan) in spiral (Helical) mode. The technical scan parameters were as follows: rotation time, 1 s; slice thickness, 1 mm; X-ray tube potential, 120 kV; and X-ray tube current, 100 mA. Transverse images were obtained through the entire nasal and cranial region. The reconstructed images were saved in DICOM format for subsequent analysis.

Image Processing

The acquisition of the image was achieved in the transverse plane, and the reconstructed images were subsequently evaluated in both bone and soft tissue windows. The window width (WW) and window level (WL) were adjusted as needed for optimal contrast and visualization of the paranasal sinus structures, with standard settings of WW = 415 and WL = 28 for soft tissues. Three-dimensional reconstruction was not performed in this study; only two-dimensional transverse images were analyzed.

Anatomical Verification

To corroborate the CT findings, two domestic goats (*Capra hircus*) were euthanized under deep anesthesia (pentobarbital overdose) and decapitated. Each head was disarticulated at the atlantooccipital joint and sectioned transversely at 1 mm intervals, corresponding to the CT slice thickness. The cross-sectional specimens were compared with the CT images and standard anatomic references to confirm sinus identity. Key cranial landmarks such as the diastema (toothless region of the maxilla), maxillary cheek teeth, orbital cavity, and zygomatic arch were used to define the rostrocaudal extent and spatial orientation of each paranasal sinus. Sinuses identified included the frontal, maxillary, palatine, lacrimal, and the dorsal, middle, and ventral conchal sinuses. All imaging and analysis were performed in accordance with established veterinary anatomical methods. Characterization between image analyses consisted of detailing the shape, boundaries, and interrelationships among these sinuses across consistent anatomical levels. All procedures were performed in accordance with institutional animal care guidelines.

Results

General Observations

CT evaluation of four adult wild goats (*Capra aegagrus*) yielded high-resolution transverse images of the nasal cavity and paranasal sinuses (Figures 1–10). Ten sequential transverse CT slices were selected from rostral to caudal orientation, with anatomical labeling based on consistent positioning in which the right and dorsal aspects of the animal corresponded to the reader’s right and upper sides, respectively (Figures 1–10). The anatomical landmarks used to describe the location and extent of the sinuses included the diastema (toothless upper jaw), maxillary cheek teeth, orbit, and zygomatic arch.

Palatine Sinus

The palatine sinus appeared as an elliptical air-filled chamber in the caudodorsal aspect of the rostral nasal cavity (Figures 1–4). It originated rostrally at the level of the diastema and terminated caudally at the level of the third maxillary cheek tooth. The sinus was most prominent at its rostral origin, where it was widest and most distinct in cross-sectional area (Figure 1).

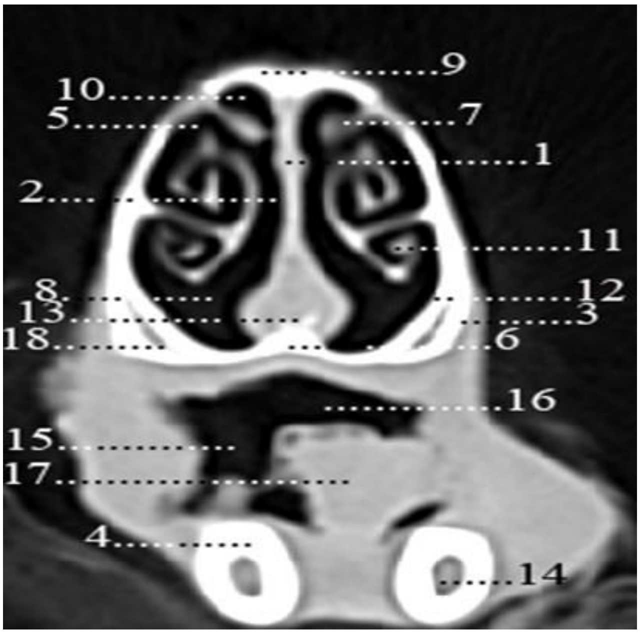

Figure 1. Transverse CT image at the level of the first maxillary cheek tooth, showing the palatine sinus (PS), ventral nasal concha (VNC), nasal septum (NS), and common nasal meatus (CNM). 1. nasal septum, 2. common nasal meatus, 3. incisive bone, 4. mandible bone, 5. middle nasal meatus, 6. palatine process of maxilla, 7. dorsal nasal concha, 8. ventral nasal meatus, 9. nasal bone, 10. dorsal nasal meatus, 11. ventral nasal concha, 12. maxillary bone, 13. vomer bone, 14. mental canal, 15. oral vestibule, 16. oral cavity, 17. tongue, 18. palatine sinus

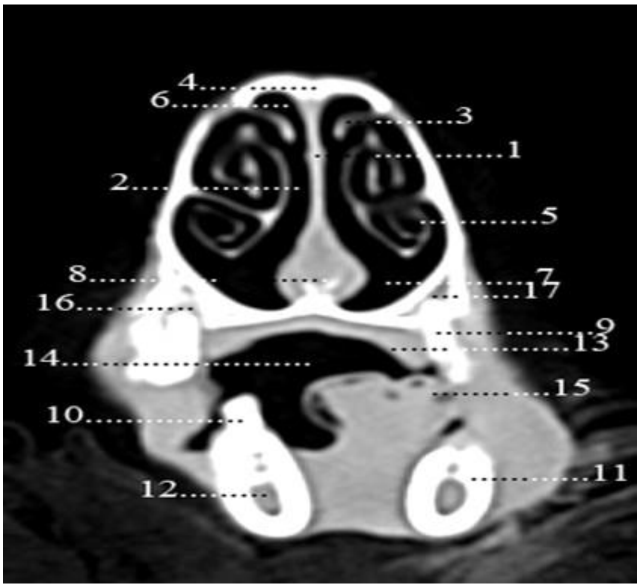

Figure 2. Transverse CT image at the level of the first cheek tooth, illustrating the nasal septum (NS) broadening caudally and the beginning of the maxillary sinus (MS). 1. nasal septum, 2. common nasal meatus, 3. dorsal nasal concha, 4. nasal bone, 5. ventral nasal concha, 6. dorsal nasal meatus, 7. ventral nasal meatus, 8. vomer bone, 9. first upper premolar teeth, 10. first lower premolar teeth, 11. mandible bone, 12. mental canal, 13. hard palate, 14. oral cavity, 15. tongue, 16. maxillary bone, 17. palatine sinus

Maxillary Sinus

The maxillary sinus was first identifiable at the level of the second maxillary cheek tooth (Figure 3), where it formed as a narrow, tapered chamber located dorsolateral to the tooth roots and medial to the infraorbital canal. Caudally, the sinus expanded in volume, reaching its maximum size around the level of the fifth cheek tooth (Figure 6). At this level, a small ventral compartment of the sinus was observed immediately rostral to the origin of the lacrimal sinus. The infraorbital canal demarcated the lateral boundary of the rostral portion of the sinus (Figures 4 and 5). Further caudally, the sinus shifted medially, creating distinct lateral and medial chambers; the medial chamber communicated dorsomedially with the nasal cavity (Figure 6). The sinus extended caudally to the rostral third of the orbit, terminating laterally at the level of the zygomatic bone (Figure 8).

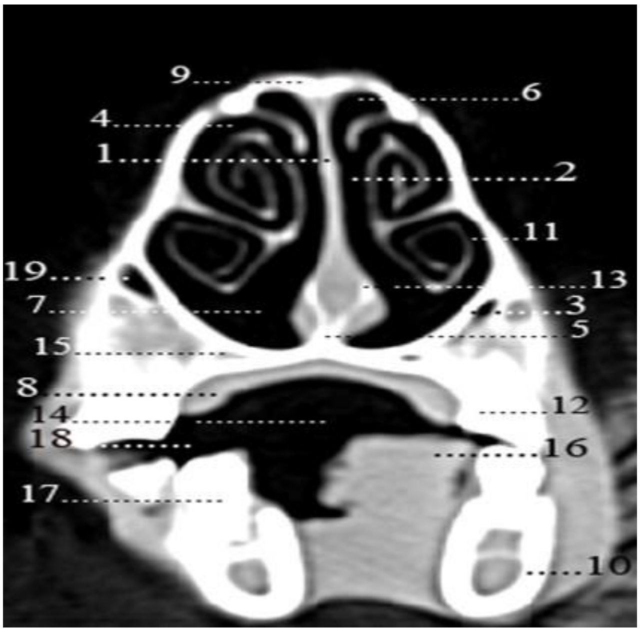

Figure 3. Transverse CT image at the level of the second cheek tooth, showing the maxillary sinus (MS) dorsolateral to the tooth root and medial to the infraorbital canal (IOC). 1. nasal septum, 2. common nasal meatus, 3. incisive bone, 4. middle nasal meatus, 5. palatine process of maxilla, 6. dorsal nasal meatus, 7. ventral nasal meatus, 8. hard palate, 9. nasal bone, 10. mandible bone, 11. ventral nasal concha, 12. second upper premolar teeth, 13. vomer bone, 14. oral cavity, 15. palatine sinus, 16. tongue, 17. first lower premolar teeth, 18. oral vestibule, 19. maxillary sinus

Frontal Sinus

The frontal sinus was situated dorsal to the level of the ethmoid cribriform plate and medial to the lacrimal sinus. It became apparent at approximately the level of the sixth maxillary cheek tooth and continued caudally to terminate adjacent to the zygomatic arch (Figures 9 and 10). In all goats, the frontal sinus was the largest single paranasal cavity, occupying a significant portion of the dorsal cranial vault in the images.

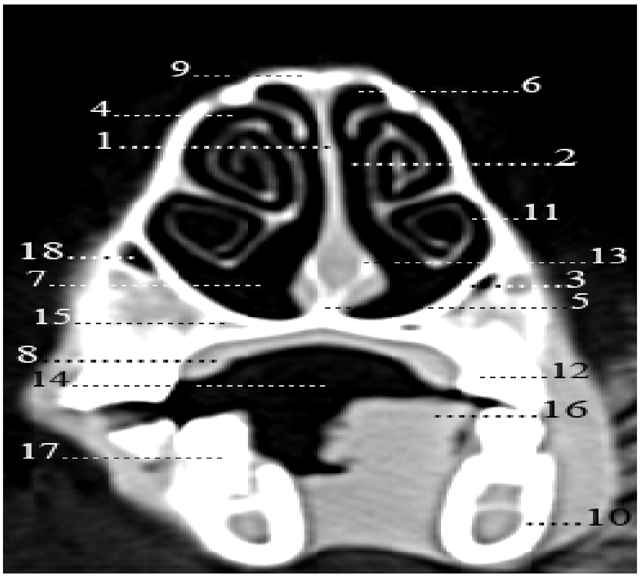

Figure 4. Transverse CT image at the level of the third cheek tooth, depicting the palatine sinus (PS), the infraorbital canal (IOC) forming the lateral boundary of the maxillary sinus (MS), and the ventral nasal meatus. 1. nasal septum, 2. common nasal meatus, 3. incisive bone, 4. middle nasal meatus, 5. palatine process of maxilla, 6. dorsal nasal meatus, 7. ventral nasal meatus, 8. hard palate, 9. nasal bone, 10. mandible bone, 11. ventral nasal concha, 12. third upper premolar teeth, 13. vomer bone, 14. oral cavity, 15. palatine sinus, 16. tongue, 17. third lower premolar teeth, 18. maxillary sinus

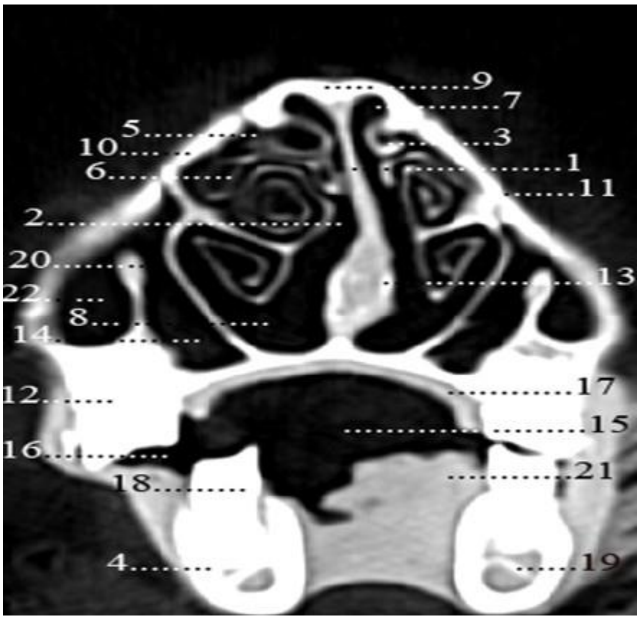

Figure 5. Transverse CT image at the level of the fourth cheek tooth, showing the division of the maxillary sinus into medial and lateral chambers and the dorsal nasal concha (DNC). 1. nasal septum, 2. common nasal meatus, 3. dorsal nasal concha, 4. mandible bone, 5. middle nasal meatus, 6. middle nasal concha, 7. dorsal nasal meatus, 8. ventral nasal meatus, 9. nasal bone, 10. lacrimal bone, 11. lacrimal canal, 12. first upper molar teeth, 13. vomer bone, 14. palatine sinus, 15. oral cavity, 16. oral vestibule, 17. hard palate, 18. first lower molar teeth, 19. mental canal, 20. infraorbital canal, 21. tongue, 22. maxillary sinus

Lacrimal Sinus

The lacrimal sinus was located rostromedially to the orbit and was visible from the level of the fifth cheek tooth to the rostral third of the orbit (Figures 6-8). It lay ventral to the dorsal compartment of the maxillary sinus, lateral to the orbital cavity, and medial to the frontal sinus. The lacrimal sinus was consistently present but relatively smaller than the maxillary and frontal sinuses; its shape and margins were nonetheless well delineated in the transverse sections (Figures 6–8).

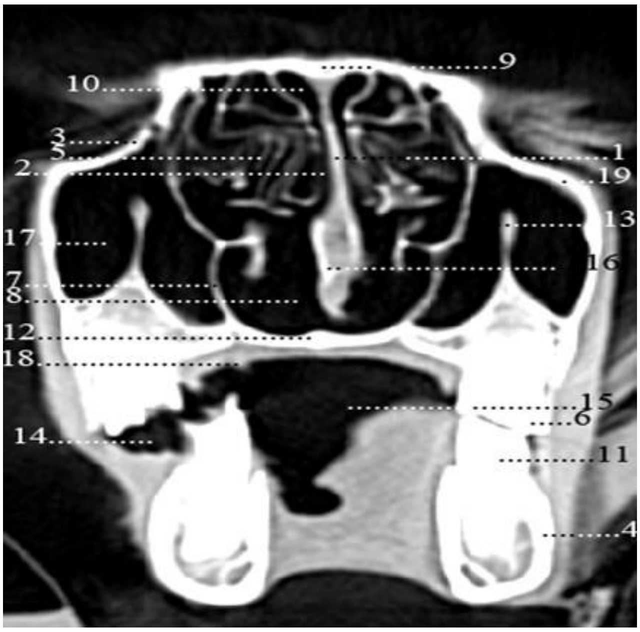

Figure 6. Transverse CT image at the level of the fifth cheek tooth, illustrating the fully expanded maxillary sinus (MS) with its medial compartment communicating with the nasal cavity (arrow) and the middle nasal concha (MNC). 1. perpendicular part of the ethmoid bone, 2. common nasal meatus, 3. lacrimal bone, 4. mandible bone, 5. ethmoidal nasal concha, 6. second upper molar teeth, 7. perpendicular part of palatine bone, 8. nasopharynx, 9. frontal bone, 10. dorsal nasal meatus, 11. lower second molar teeth, 12. palatine bone, 13. infraorbital canal, 14. oral vestibule, 15. oral cavity, 16. vomer bone, 17. maxillary sinus, 18. hard palate, 19. lacrimal bone

Nasal Conchae and Conchal Sinuses

All three nasal conchae (dorsal, middle, and ventral) and their associated sinuses were clearly discernible in the CT images. The dorsal nasal concha appeared as a scroll-like mucosal lamina in the rostral nasal cavity, becoming solid and terminating near the level of the fifth cheek tooth (Figures 1 and 5). Its associated dorsal conchal sinus extended from the level of the third to the fifth cheek tooth and was delineated as a small air-filled chamber within the conchal lamellae (Figures 4-6). The middle nasal concha was a short but robust structure, spanning the region between the fourth and sixth cheek teeth (Figures 5-7). It was almost entirely spacious, with the greatest part at the level of the fifth cheek tooth (Figure 6). The ventral nasal concha originated from the maxillary bone in the anterior nasal cavity and extended caudally to the level of the sixth cheek tooth. Its internal cavity, bordered by two scroll-like lamellae, was most clearly visible from the first to fourth cheek teeth (Figures 1-7).

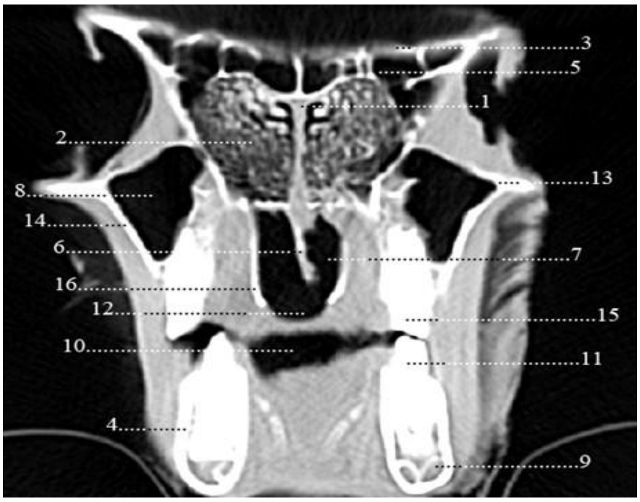

Figure 7. Transverse CT image at the level of the sixth cheek tooth, depicting the frontal sinus (FS) and parts of the middle and ventral conchae. 1. perpendicular part of the ethmoid bone, 2. cribriform plate, 3. frontal bone, 4. mandible bone, 5. frontal sinus, 6. vomer bone, 7. nasopharynx, 8. maxillary sinus, 9. mental canal, 10. oropharynx, 11. third lower molar teeth, 12. nasopharynx, 13. zygomatic arch, 14. zygomatic bone, 15. third upper molar teeth, 16. pterygoid plate

Nasal Septum

The nasal septum appeared as a narrow, vertically oriented plate arising from the floor of the nasal cavity (Figure 1). As the ventral portion of the nasal cavity widened caudally, the septum's breadth increased proportionally (Figure 2). Notably, the septum was flanked by two distinct mucosal folds between the first and fourth cheek teeth (Figures 2-5), partially dividing the medial portion of the ventral nasal meatus. These folds became progressively less distinct caudally and were no longer clearly discernible as discrete structures in the CT images by the level of the third cheek tooth (Figure 4). At the level of the fifth cheek tooth, a small midline communication (foramen) was observed between the left and right nasal chambers (Figure 6), providing a connection between the two sides of the nasal cavity.

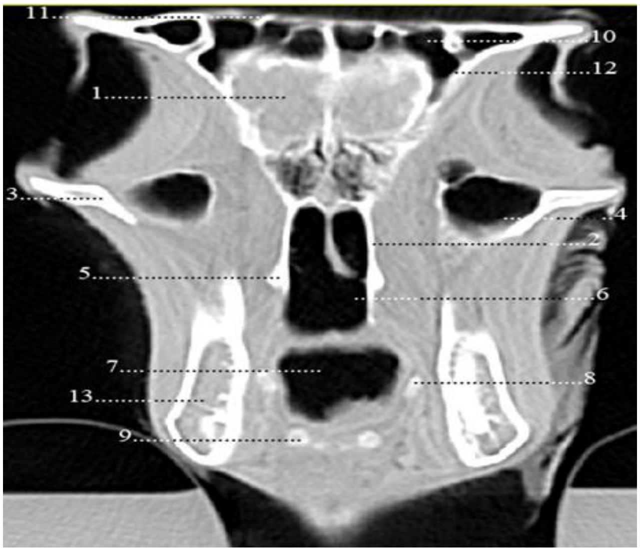

Figure 8. Transverse CT image at the level of the orbit, showing the zygomatic arch (ZA) and the caudal extent of the maxillary sinus (MS). 1. brain, 2. pterygoid plate, 3. zygomatic arch, 4. maxillary bulla, 5. pterygoid plate, 6. nasopharynx, 7. oropharynx, 8. ceratohyoid bone, 9. thyrohyoid bone, 10. frontal sinus, 11. frontal bone, 12. sphenoid bone, 13. mental canal

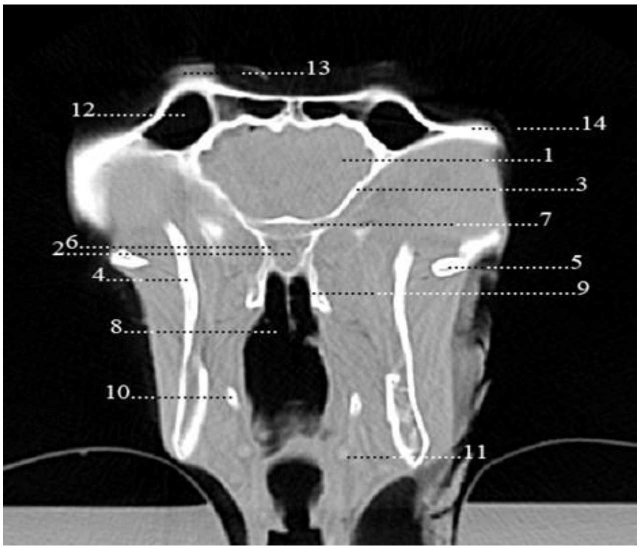

Figure 9. Transverse CT image at the level of the optic chiasma and sphenoid region, demonstrating the basisphenoid and sphenoid bones, pterygoid plate, and the caudal extent of the frontal sinus (FS) with the corneal process and zygomatic process of the frontal bone. 1. brain, 2. basisphenoid bone, 3. sphenoid bone, 4. ramus of mandible, 5. zygomatic arch, 6. orbitorotundom foramen, 7. optic chiasma, 8. pharynx, 9. pterygoid plate, 10. ceratohyoid bone, 11. thyrohyoid bone, 12. frontal sinus, 13. corneal process, 14. zygomatic process of the frontal bone

The overall positioning, extent, and structural relationships of the paranasal sinuses are summarized in Table 1, offering a comparative reference across anatomical levels. Each of the sinuses and anatomical features described above was consistently identified in all four wild goat specimens. The spatial relationships among the sinuses observed on CT closely matched those seen in the anatomical sections, though several notable differences in sinus size and shape were observed.

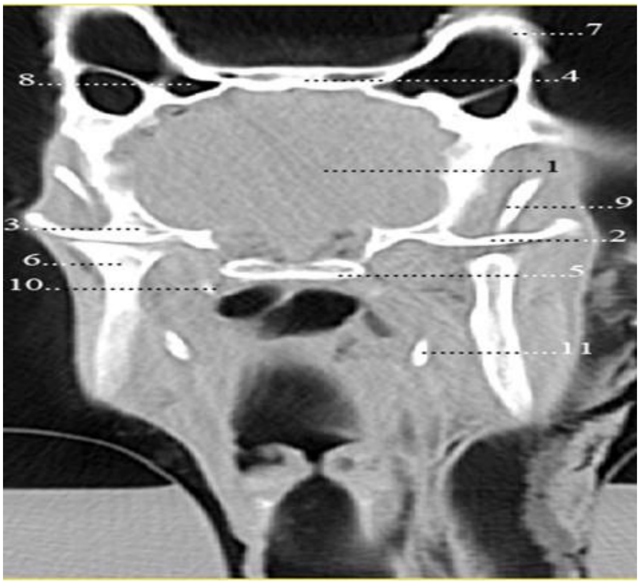

Figure 10. Transverse CT image at the most caudal level (just rostral to the orbit), illustrating the frontal sinus (FS) adjacent to the zygomatic arch (ZA). 1. brain, 2. squamous part of temporal bone, 3. retroarticular foramen, 4. frontal bone, 5. basioccipital bone, 6. condylar process, 7. corneal process, 8. frontal sinus, 9. coronoid process, 10. stylohyoid bone, 11. thyrohyoid bone

Discussion

CT imaging has clarified the paranasal sinus anatomy of domestic small ruminants, but little is known about wild goats. For example, Shojaei et al. (2008) provided a CT atlas of Rayini goat sinuses (*Capra hircus*) (19), and Tohidifar et al. (2020) detailed the Saanen goat skull CT anatomy (20). Similarly, CT studies of domestic sheep have been reported (8, 9, 16, 21, 22, 24). In contrast, we found no prior tomographic study focused on the wild goat (*Capra aegagrus*), leaving a clear gap in the comparative anatomy literature. This lack of species-specific data hinders precise comparative analysis and may limit veterinary care tailored to wild goats. Using high-resolution CT scans, we were able to delineate and identify all of the major paranasal sinuses in *Capra aegagrus*. Specifically, the palatine, maxillary, frontal, lacrimal, and conchal sinuses were clearly visualized on the CT images. For instance, the palatine sinus ran caudally down the hard palate, whereas the frontal sinus was large and occupied the majority of the frontal bone. The lacrimal sinus formed a small recess in the lacrimal bone close to the orbit, and the dorsal and middle conchal sinuses followed the dorsal and middle nasal turbinates, respectively. Interestingly, we discovered an opening between the palatine and maxillary sinuses. These results are consistent with a general pattern seen in goats. The maxillary, frontal, palatine, lacrimal, and conchal sinuses in domestic goats were also identified by Shojaei et al. (2008) (19). In all cases, the various sinuses and their connections were consistently identifiable on CT sections. This methodological approach aligns with previous efforts to develop tomographic anatomical atlases in wild ruminants, which emphasized the clinical value of species-specific CT anatomy for wildlife medicine and conservation planning (18, 25, 26).

Our research shows that the frontal sinus in wild goats is a well-developed cavity that extends dorsally into the frontal bone, occupying a significant part of the cranial vault. This morphology fits well with the idea that these sinuses help to absorb or spread out the mechanical forces involved in head-butting behavior. Farke found that goats and bighorn sheep have different layouts in their frontal sinuses. He also found that bighorn sheep have more widespread pneumatization and may be better at adapting to fighting. He came to the conclusion that the shape and size of the sinuses are connected to the way the skulls are stressed (24). These comparisons further underscore the importance of documenting species-specific sinus structures to infer possible functional and evolutionary adaptations.

Our results generally confirmed previously reported sinus arrangements of the domestic Caprinae, with a few notable differences. Both wild and domestic goats possessed prominent frontal and maxillary sinuses, but wild goats also had a well-developed palatine sinus. Such a finding contrasts with Saanen goats, in which Tohidifar et al. (2020) found no palatine (or sphenoidal) sinus (20). Likewise, Awaad et al. (2019) reported that Egyptian Baladi sheep have an “unnoticeable” palatine sinus (21). In our wild goats, the palatine sinus was consistently present and substantial, suggesting a species-level variation not seen in some domestic breeds. Unlike in wild goats, where the lacrimal sinus was consistently present despite its small size, this structure is often variable or even vestigial in some domestic breeds, such as the Baladi sheep or Saanen goat (20, 21). The lacrimal sinus in wild goats was relatively small, echoing findings in domestic goats: in Saanen goats, the lacrimal sinus was the smallest paranasal cavity (20), a pattern we also observed. Overall, *Capra aegagrus* shares the basic sinus complement (maxillary, frontal, lacrimal, palatine, conchal) seen in *Capra hircus*, but with slight differences in the relative development of palatine and lacrimal sinuses. For instance, previous authors noted that Rayini goats lack a maxillopalatine communication (22), whereas our CT images clearly showed a palatomaxillary aperture linking the palatine and maxillary sinuses. In summary, our findings validate much of the known anatomy of domestic goats and sheep, while also expanding it by revealing that wild goats possess a distinctive palatine sinus and specific sinus connections that merit further investigation.

Table 1. Anatomical location and rostrocaudal extent of the paranasal sinuses in the wild goat (*Capra aegagrus*) relative to the maxillary cheek teeth, orbit, and zygomatic arch.

Landmark / Structure	Toothless Part of Upper jaw	1st cheek tooth	2nd cheek tooth	3rd Cheek tooth	4th cheek tooth	5th cheek tooth	6th cheek tooth	Rostral part of orbit	Caudal Part of orbit	Zygomatic Arch
Palatine sinus	+	+	+	+	-	-	-	-	-	-
Maxillary sinus	-	-	+	+	+	+	+	+	-	-
Lacrimal sinus	-	-	-	-	-	+	+	+	+	-
Frontal sinus	-	-	-	-	-	-	+	+	+	+
Dorsal conchal sinus	-	-	-	+	+	+	-	-	-	-
Middle conchal sinus	-	-	-	-	+	+	+	-	-	-
Ventral conchal sinus	+	+	+	+	+	+	+	-	-	-

This study presents some limitations that should be acknowledged. First, the small sample size—limited to only four wild goat skulls—restricts the ability to fully assess natural anatomical variation related to age, sex, or subspecies. Consequently, individual variation in sinus structures, such as differences in extent or shape, cannot be ruled out. The lack of sophisticated three-dimensional reconstructions or accurate morphometric analysis constrained our ability to make quantitative comparisons of sinus volume, shape, or size. Consequently, the evaluation of sinus anatomy in this work is predominantly descriptive and qualitative. Furthermore, all the samples we studied came from individuals who were clinically normal and showed no signs of disease. As a result, our findings may not apply to cases where the sinuses are affected by illness or other abnormalities. Without the inclusion of cases involving sinusitis, neoplasia, or trauma, the findings cannot be directly extrapolated to clinical diagnosis or surgical planning in affected individuals. Overall, these limitations constrain the generalizability of our CT atlas to the broader *Capra aegagrus* population and clinical practice. Therefore, caution is advised against generalizing these findings to other individuals, breeds, or pathological contexts without confirmation by further data. Future research must place an emphasis on broader sampling of a more diverse population, including individuals of varying subspecies, ages, and sexes, to more fully reflect the natural anatomical variation that exists within the species. As emphasized by Masoudifard et al. (2022), expanding the range of animals and breeds studied is essential for achieving a comprehensive understanding of sinus anatomy (23). Such an approach would not only strengthen the anatomical baseline but also enhance its clinical relevance for a broader range of cases. Additionally, applying volumetric CT reconstruction (as recently done in sheep (22)) would provide precise measurements of sinus volumes and surface areas in wild goats. Three-dimensional models would allow demonstration of subtle shape differences and numerical quantification of morphometric data. This data would enable robust quantitative comparisons and may uncover small morphological variations not apparent through conventional 2D imaging. Comparative morphometric analyses of wild goats, domestic goats, and sheep would yield essential insights into the influence of evolutionary history and environmental factors on sinus development in caprine and ovine species. For example, these analyses could help explain why wild goats consistently exhibit a prominent palatine sinus, whereas some domestic breeds do not. Such information would be of benefit to both evolutionarily informed biology and selective breeding programs. Correspondingly, investigating CT scans of wild goats with known sinonasal pathologies such as sinusitis, neoplasia, or trauma would reveal the clinical significance of this normative anatomy. A definitive reference framework enables veterinarians to more precisely identify anomalies, evaluate disease development, and devise suitable medicinal or surgical interventions. Overall, further research along these dimensions will refine both anatomical knowledge and clinical outcomes for populations of wild goat.

Conclusion

This CT-based study establishes a detailed paranasal sinus anatomy for the wild goat (*Capra aegagrus*). By delineating the palatine, maxillary, frontal, lacrimal, and conchal sinuses and their interconnections, we provide a foundational anatomical baseline for this species. Such a reference is valuable for veterinary care (e.g., surgical planning, disease diagnosis) in wild goats. Moreover, knowing the precise sinus anatomy of *C. aegagrus* will aid conservation-oriented veterinary work (health assessments of wild populations, planning for rehabilitation or translocation) by enabling species-specific care. In summary, our findings fill a critical gap: they both confirm known caprine sinus patterns and highlight species-specific features of the wild goat, thereby informing clinical practice and supporting future anatomical and conservation research.

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Author Contribution

Seyed Mohsen Sajjadian: Conceptualization, Project Administration, Methodology, Supervision, Investigation (CT Imaging & Data Acquisition), Formal Analysis, Data Curation, Original Draft, Writing – Review & Editing. **Bahador Shojaei:** Conceptualization, Project Administration, Methodology, Supervision, Investigation (CT Imaging & Data Acquisition), Formal Analysis, Data Curation, Original Draft, Writing – Review & Editing. **Mohammad Reza Esmailinejad:** Review & Editing. **Zohreh Pouraminaei:** Investigation, Formal Analysis, Data Curation, Original Draft. **Masoud Abedi:** Writing – Review & Editing, Investigation, Formal Analysis.

Data Availability

All data generated or analyzed during this study are included in this published article [and its additional files].

Ethical Approval

All animal experiments conducted in this study were reviewed and approved by the Research Ethics Committee of Shahid Bahonar University of Kerman, Kerman, Iran, ensuring compliance with ethical standards.

Conflict of Interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Consent for publication

Not applicable.

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