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Cross-Sectional Morphology and 3D Computed Tomography of the Head in the European Badger (*Meles meles*)

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ABSTRACT

The present investigation explores the cranial anatomy of the European badger (*Meles meles*) through computed tomography (CT), aiming to fill existing gaps in wild-carnivore osteology and supply a reliable imaging benchmark for veterinary practice. Given the limited CT-based documentation of mustelid skulls, this work addresses a critical need for precise anatomical references in wildlife medicine. Five adult female cadavers (body mass 8.85–10.32 kg), collected in Semnan Province, Iran, underwent high-resolution scanning (Siemens Somatom Spirit). Volume-rendered 3D models and multiplanar transverse slices disclosed a stout zygomatic arch, an enlarged infraorbital foramen, and sharply defined external sagittal and nuchal crests—features linked to powerful mastication and burrowing. The frontal sinus appeared expansive, conferring structural rigidity, whereas the maxillary recess and sphenoid sinus were compact yet distinct. Within the nasal cavity, elongated dorsal nasal conchae, a midline septum, and a robust vomer with pronounced ventral grooves collectively optimize olfactory performance. Unlike earlier linear morphometric reports, these volumetric data reveal previously undescribed internal compartmentalization and spatial relationships. The study thus furnishes a diagnostic foundation for cranial trauma, neoplasia, and sinus pathology in wild carnivores while highlighting CT's superiority in capturing species-specific functional morphology.

Introduction

The European badger *(Meles meles)* is a common and widespread species. Badgers play an important part in various interspecific interactions depending on their diet, behavior, prey-predator interactions, disease dispersal, etc. Badger is one of the mammal species that belongs to the family of marten *(Mustelidae*) and the order Carnivora. Badger has a characteristic black and white striped face with white-tipped ears.[1] Modern imaging modalities, such as computed tomography (CT), enable fast visualization of animal anatomy. CT images provide differential appearance of bone, soft tissues, sinuses and cavities according to their radiodensity.[2]

The skull constitutes the cranial skeleton, safeguarding the brain, sensory organs (eyes and ears), paranasal sinuses, and dentition. Concurrently, morphological disparities between the skull and mandible influence the cross-sectional area of masticatory muscles, thereby determining bite force.[3] While computed tomography (CT) imaging has been extensively employed to study the cranial anatomy of domestic carnivores, such as dogs and cats, comparable research on wild carnivores remains limited. Previous studies have utilized CT imaging to investigate the cranial morphology of various carnivore species, including leopards, lions, and foxes.[4-6] Additionally, morphometric analyses of the badger skull have been

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conducted, though these differ in scope from the present study.[7] Additionally, Rasouli *et al.* (2025) documented the characteristics of skull bones in a study employing a methodology fundamentally distinct from that of the present investigation.[8]

Comparing the information obtained in this study with similar animals will improve our understanding of carnivore anatomy using new techniques. The objective of the present study was to examine the intricacies of the badger's head using CT scans and to link these images with anatomical cross-sectional pictures. The findings of the current study will serve as an anatomical reference for the badger's head. This work also establishes a foundation for the interpretation of CT imaging in the clinical applications concerning the badger head. It is a suitable method for diagnosing various types of neoplasms, trauma, infectious and non-infectious inflammatory diseases in the head region.[9,10] In cases of nasal foreign bodies, CT often shows sinus involvement with secondary changes like hyperattenuation, aiding in differentiation from neoplasia or rhinitis.[11] Veterinarians and surgeons specializing in zoo animals and wildlife must possess fundamental anatomical understanding of the species they treat, including the badger. The absence of this understanding leads to inferior care for these patients.[12]

Materials and Methods

We conducted the current study using 5 female badger cadavers, weighing 8.85-10.32 kg. The Environmental Organization discovered these cadavers in the natural surroundings of Semnan, Iran, and transferred them to the Faculty of Veterinary Medicine's anatomy hall. The cadavers showed no damage, and the dental formula (I3/3, C1/1, P4/4, 198 M1/2 = 38) confirmed the animal's maturity.[1] We sectioned the head at the level of the C2-C3 intervertebral space. The heads were then fixed in an embalming solution: 10% formaldehyde (1.5 litre), glycerin (3 L), methyl alcohol (12.5 L), and phenol (1 L) for 7 days under refrigeration. We then used the badgers for CT studies.

We took samples for CT scan imaging as quickly as possible (less than five hours) and prepared images of both longitudinal and transverse sections. We took the transverse section images perpendicular to the palatine bone, using the cheek teeth as a guide for image position. We used the Siemens, Germany-manufactured Somatom Spirit model CT scan machine to conduct this study. The device's technical settings were 100 kV, 71 mA, 400 window level, 2000 window width, and 1- second scan duration. CT images were used to reconstruct volume-rendered (VR) 3D CT reformatted images for the skull using multiplanar reconstructions[4]. Morphological characteristics were evaluated, and *Nomina Anatomica Veterinaria* was used as terminology in the study.

Results

MIP CT Reconstruction Image

Figure 1 represents the MIP (maximum-intensity projection) reconstruction of the badger's head in the form of a sagittal image. In this image, the structures related to the sinuses and conchae inside the nasal cavity were clearly visible. The frontal and ecto-turbinate were well-developed. Also, a distinct small sphenoid sinus was observed above the presphenoid bone. The dorsal nasal concha was observed throughout its entire length, reaching its maximum dimension in the middle area of the nasal cavity and becoming thinner as it approached its

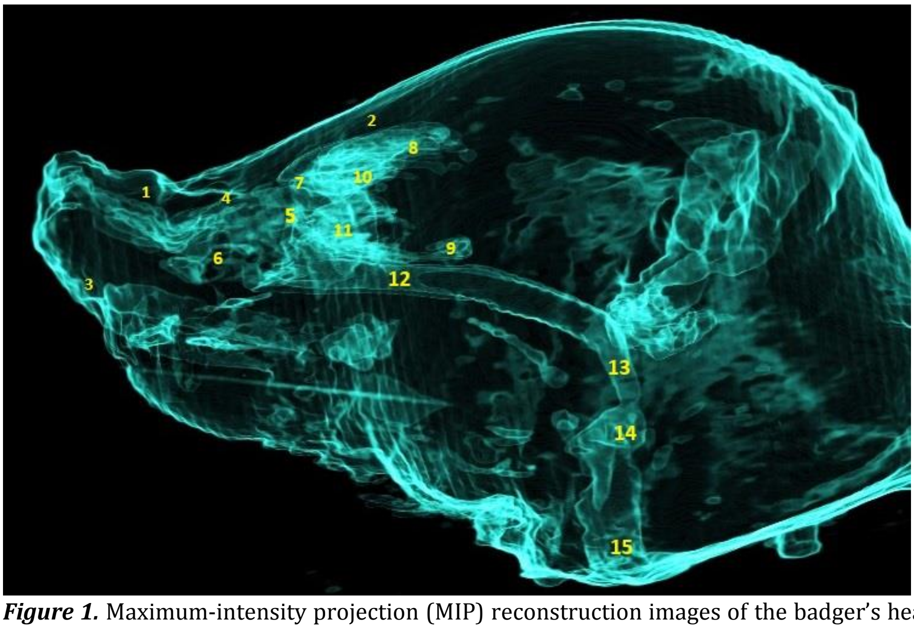

Figure 1. Maximum-intensity projection (MIP) reconstruction images of the badger's head. Sagittal image. Left lateral view. 1. Nasal bone, 2. Frontal bone, 3. Incisive bone, 4. Dorsal concha, 5. Middle concha, 6. Ventral concha, 7. Ethmoidal bone: Cribriform plate, 8. Frontal sinus, 9. Sphenoid sinus, 10. Ecto-turbinates, 11. Endo-turbinates, 12. Presphenoid bone, 13. Soft plate, 14. Larynx: arytenoid cartilage, 15. Trachea.

rostral extremity. The ventral nasal concha was limited to the caudal half of the nasal cavity and wasn't connected to endo-turbinate. The middle concha was also limited to the caudal regions of the nasal cavity.

Volume-Rendered 3D-Reconstructed Images

The volume-rendered three-dimensional (3D) reconstructions of the European badger head enabled the identification of various cranial and facial bones, along with their associated anatomical features (Figure 2). The zygomatic process of the temporal bone (TZ) formed a robust linkage with the temporal process of the zygomatic bone (ZT), resulting in a visibly zygomatic arch. Although the external acoustic meatus possessed a relatively broad opening. Additionally, the mastoid process showed substantial growth in the area behind the external acoustic meatus. The rudimentary frontal process of the zygomatic bone (FZ) and the short zygomatic process of the frontal bone (ZF) were positioned at a significant interval from one another near the orbit's caudal border. A prominently visible and sizable infraorbital foramen was located above the sockets of the third and 4th premolar teeth (Figure 2a).

A single, elongated, and sturdy vomer bone was observed protruding into the nasal cavity at its front, articulating seamlessly with the premaxilla, presphenoid, and maxillary bones. A deep groove was evident along its borders. In this view, the width of the infraorbital foramen is clearly evident (Figure 2b). The nuchal region and interparietal bone exhibited a roughly triangular shape. The foramen magnum displayed a circular configuration. The nuchal crest, situated along the upper edge of the squamous occipital bone, featured a pronounced bow-like curve, while the rounded mastoid process was highly developed and seamlessly integrated with the crest's lower extremities on both sides. The jugular processes in the badger were characterized by their small size and pointed tips (Figure 2c).

When viewed from dorsal, the frontal, nasal, and parietal bones were clearly discernible. A striking feature was the prominent external sagittal crest, appearing as a seamless continuous ridge. In 3D CT scan images, in some specimens this crest was seen as separate from the rest of the skull bone, which appears to have been due to the animal's immaturity. Distinct temporal lines extended forward from this crest, linking to the zygomatic process of the frontal bones and defining the caudal edge of the orbit. The parietal bones took the shape of two irregular triangles, a configuration that contributed to the restricted growth of the frontal bones. A curved temporal fossa stretched across the external sagittal crest, serving as a key anatomical landmark. At the rear of the external sagittal crest, the nuchal crest stood out prominently. The interparietal bone was fully fused into this crest, lacking a distinct separation. The inter-incisive canal was not detected in our observations (Figure 2d).

Transverse CT Images

In transverse anatomical sections, the structures of the oral cavity, nasal cavity, and paranasal sinuses were distinctly identifiable (Figure 3). The nasal cavity of badger was bisected by a median nasal septum into two symmetrical halves, comprising a well-developed cartilaginous plate extending anteriorly to the level of the 2nd lower premolar for approximately two-thirds of its length, and a thin bony plate in the posterior third

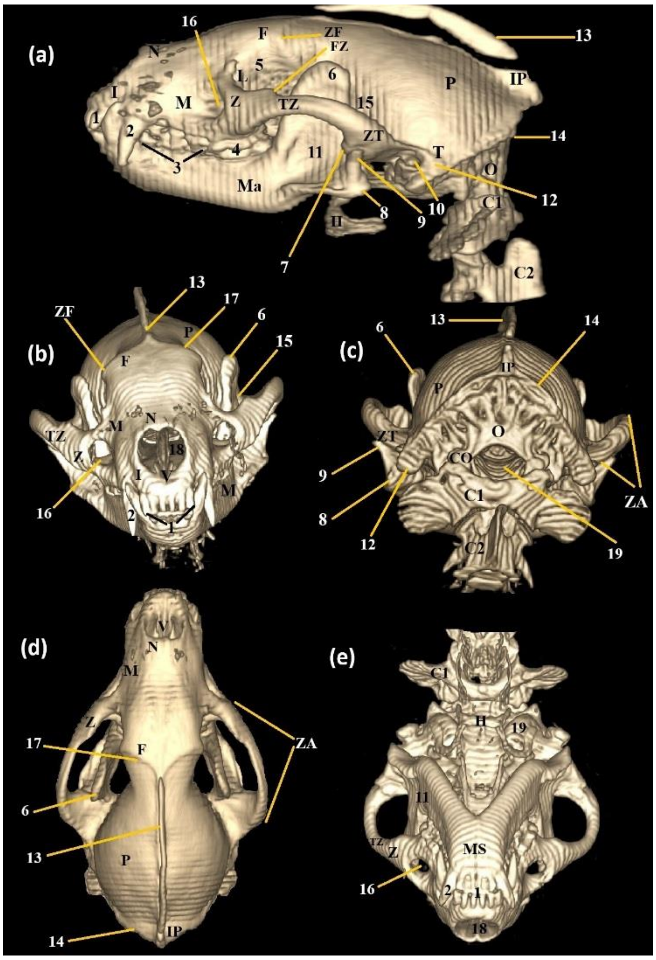

Figure 2. Volume-rendered 3D reconstruction of badger skull (a)lateral view, (b)rostral view, (c)caudal view, (d)dorsal view, (e)ventral view. I. Incisive bone, N. Nasal bone, M. Maxilla, Ma. Mandible Z. Zygomatic bone, L. Lacrimal bone, F. Frontal bone, P. Parietal bone, T. Temporal bone, IP. Interparietal bone, O. Occipital bone, CO. Condyle of occipital, TZ. Temporal process of zygomatic bone, ZT. Zygomatic process of temporal bone, ZA. Zygomatic arch, ZF. Zygomatic process of frontal bone, FZ. Frontal process of zygomatic bone, C1. 1ST Cervical vertebrae, C2. 2ND Cervical vertebrae, MS. Mandibular symphysis, H. Hyoid bone, V. Vomer bone, 1. Incisor teeth, 2. Canine teeth, 3. Premolar teeth, 4. Molar tooth, 5. Orbital cavity, 6. Coronoid process of mandible, 7. Mandibular notch, 8. Angular process of mandible, 9. Condyloid process of mandible, 10. External acoustic meatus, 11. Masseteric fossa, 12. Mastoid process, 13. External sagittal crest, 14. Nuchal crest, 15. Temporal fossa, 16. Infraorbital foramen, 17. Temporal fossa, 18. Nasal aperture, 19. Tympanic bulla.

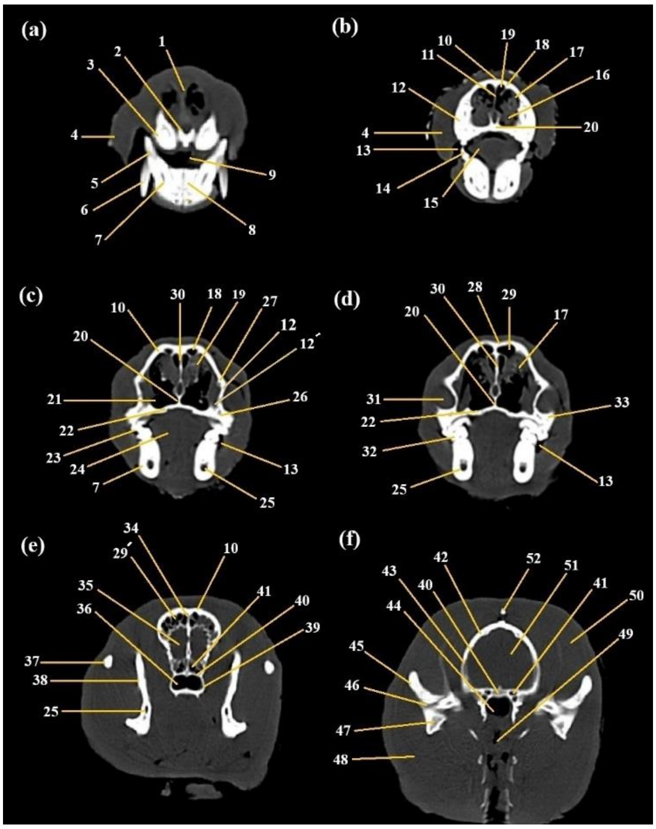

Figure 3. Transverse CT scans and the most closely corresponding anatomic sections of European badger head: (a) at the level of lower canine teeth, (b) at the level of the 2nd lower premolar teeth, (c) at the level the rostral border of 4th lower premolar teeth, (d) at the level of middle of 4th lower premolar teeth, (e) at the level of the rostral border of coronoid process, (f) at the level of temporomandibular joint. 1. Nasal cartilages, 2. Vomer bone, 3. Incisive bone, 4. Upper lip, 5. Lower canine tooth, 6. Upper canine tooth, 7. Mandible, 8. Incisor teeth, 9. Mouth proper cavity, 10. Nasal bone, 11. Cartilaginous nasal septum, 12. Maxilla, 12´. Maxillary recess, 13. Buccal vestibule, 14. 2nd lower premolar teeth, 15. Tongue, 16. Ventral concha, 17. Dorsal concha, 18. Ethmoidal crest, 19. Dorsal meatus, 20. Nasal crest, 21. Right nasal cavity, 22. Palatine process of maxilla, 23. Rostral border of 4th lower premolar teeth, 24. Sublingual muscle, 25. Mandibular canal, 26. Infraorbital canal, 27. Nasolacrimal canal, 28. Frontal bone, 29. Rostral part of frontal sinus, 29´. Caudal part of frontal sinus 30. Osseus nasal septum, 31. Orbital cavity, 32. 4th lower premolar teeth, 33. Zygomatic bone, 34. Frontal septum, 35. Olfactory bulb of brain, 36. Choana, 37. Temporal process of zygomatic bone, 38. Ramus of mandible, 39. Pterygoid bone, 40. Presphenoid bone, 41. Sphenoid sinus, 42. Parietal bone, 43. Temporal bone, 44. Nasopharynx, 45. Zygomatic process of temporal bone, 46. Temporomandibular joint, 47. Condyloid process of mandible, 48. Masseteric muscle, 49. Oropharynx, 50. Temporal muscle, 51. Cerebrum, 52. External sagittal crest.

(Figures 3a and 3b). The ventral concha was predominantly situated in the posterior half of the nasal cavity. The dorsal concha was elongated, spanning the nasal cavity from its rostral boundary to the distal two-thirds. The middle concha was restricted to the distal third of the nasal cavity and appeared to integrate with the ethmoidal concha (Figures 3c and 3d).

The maxillary recess does not meet the criteria for a true sinus, as it is formed between distinct bones rather than within the plates of the maxilla. This restricted space was narrowly positioned in the ventral region of the maxillary body, located dorsal to the infraorbital canal. The recess communicated with the ventral nasal meatus via a broad nasomaxillary opening, positioned at the level of the 4th lower premolar teeth (Figure 3c).

The frontal sinus exhibited a notably expansive area, with its rostral boundary positioned anterior to the 4th premolar and its caudal boundary aligned with the posterior margin of the coronoid process zygomatic arch. A bony frontal septum partitioned the sinus into distinct right and left cavities. Each cavity was further delineated into rostral and caudal regions. The rostral region consisted of a single, undivided large cavity, whereas the caudal region was characterized by slender radiopaque partitions that subdivided it into multiple radiolucent compartments of varying sizes (Figures 3d and 3e).

The sphenoid sinus was divided by a midline septum into distinct left and right sphenoid sinuses. Each sinus was further subdivided by a thin bony partition into medial and lateral compartments. Positioned immediately inferior to the olfactory bulbs, the sinus also featured a single, prominent choanal foramen located ventrally (Figure 3e).

Discussion

The volume-rendered three-dimensional (3D) reconstructions of the European badger (*Meles meles*) head (Figure 2) provide a comprehensive visualization of cranial and facial bones, elucidating key anatomical features and their functional implications. These reconstructions, enabled by advanced computed tomography (CT) imaging, offer high-resolution insights into the badger's skull morphology, facilitating comparisons with other carnivores and highlighting species-specific adaptations. The findings, including the robust zygomatic arch, prominent infraorbital foramen, and distinct cranial crests, contribute to a deeper understanding of mustelid cranial anatomy and its clinical relevance.

The zygomatic arch, formed by the articulation of the zygomatic process of the temporal bone and the temporal process of the zygomatic bone, was notably robust, reflecting its role in supporting masticatory muscles and contributing to bite force. This robust configuration is consistent with observations in other carnivores, such as canids and felids, where a strong zygomatic arch correlates with powerful mastication.[5,13] However, the badger's relatively broad external acoustic meatus and well-developed mastoid processes suggest adaptations for enhanced auditory sensitivity and head stability, potentially linked to its fossorial lifestyle. In contrast, felids like leopards (*Panthera pardus*) exhibit a narrower external acoustic meatus, prioritizing cranial streamlining for predation.[4] In some cat breeds, a significant size difference has been observed between the auditory and olfactory structures in males and females, which could also be evaluated in future studies regarding badgers.[14]

The rudimentary frontal process of the zygomatic bone and the short zygomatic process of the frontal bone, positioned at a significant interval near the orbit's caudal border, indicate a less pronounced orbital framework compared to larger carnivores. For instance, lions (*Panthera leo*) display a more integrated orbital structure, enhancing eye protection during hunting.[5] The badger's configuration may reflect a balance between cranial weight reduction and structural support, suited to its burrowing behavior. The large infraorbital foramen in the badger suggests enhanced sensory innervation, likely supporting vibrissal sensitivity for navigating burrows and foraging in low-light environments.This is comparable to findings in foxes*(Vulpes vulpes)* and Iranian brown bear (*Ursus arctos*), where a sizable infraorbital foramen supports vibrissal sensitivity for environmental interaction.[6,15]

The vomer bone, observed as a single, elongated structure protruding into the nasal cavity with seamless articulation to the premaxilla, presphenoid, and maxilla, is consistent with its role in stabilizing the nasal septum. The deep grooves along its borders, visible in 3D reconstructions, suggest increased surface area for mucosal attachment, a feature also noted in dogs (*Canis lupus familiaris*) but less pronounced in mustelids like otters (*Lutra lutra*).[7] This morphological trait may enhance olfactory efficiency, critical for the badger's foraging and social behaviors.[1]

The nuchal region and interparietal bone's triangular shape, combined with a circular foramen magnum and a pronounced, bow-like nuchal crest, indicate robust occipital support for neck musculature. The integration of the well-developed mastoid process with the nuchal crest's lower extremities mirrors findings in other carnivores with strong head movements, such as wolves (*Canis lupus*).[5] The small, pointed jugular processes, however, are a distinguishing feature, contrasting with the broader jugular processes in felids, which support greater cranial mobility.[13]

Dorsally, the prominent external sagittal crest, appearing as a continuous ridge in mature specimens but detached in some immature ones, reflects ontogenetic variability in cranial suture fusion. This is consistent with morphometric studies of badgers, which note age-related differences in crest development.[7] The temporal lines extending from the sagittal crest to the zygomatic process of the frontal bones define the orbit's caudal edge, a feature shared with canids but less pronounced in felids due to their rounded skulls.[6] The parietal bones' irregular triangular shape, limiting frontal bone expansion, and the curved temporal fossa are key landmarks that align with biomechanical requirements for muscle attachment in carnivores.[8]

The absence of the interincisive canal in the badger, as observed in this study, contrasts with its presence in some canids, where it facilitates vascular supply to the premaxilla.[16] This absence may reflect a simplified vascular architecture in mustelids, warranting further investigation. The full fusion of the interparietal bone into the nuchal crest, lacking distinct separation, further distinguishes the badger from species like foxes, where partial separation is common in younger individuals[6]. Cats show no such canal absence, with consistent vascular features in their mesocephalic skulls.[17]

Large frontal sinuses in carnivores like tigers, lions, leopards, and spotted hyenas reduce skull weight while maintaining structural integrity to support powerful bite forces. In hyenas, they specifically aid in bone-crushing by distributing mechanical stress. Small-sized sphenoid sinus suggests a minor role compared to frontal sinuses, with limited impact on respiratory or sensory functions. A comprehensive comparison between these sinuses in different carnivores is presented in Table 1.[18-20]

Comparatively, Rasouli *et al*. (2025) documented badger skull bones characteristics using a morphometric approach, focusing on external measurements rather than the detailed internal and 3D structural analyses

Table 1. Comparison of paranasal sinuses in different carnivore species.

Species	Frontal sinus	Maxillary recess	Sphenoid sinus
European badger *(Meles meles)*	Present (well-developed)	Present (narrow recess)	Present (small)
Tiger (*Panthera tigris*)	Present (large, supports cranial structure)	Present (narrow recess)	Present (small)
Lion (*Panthera leo*)	Present (large, supports jaw muscles)	Present (narrow recess)	Present (small)
Leopard (*Panthera pardus*)	Present (well-developed)	Present (recess-like)	Present (small)
Domestic dog (*Canis lupus familiaris*)	Variable (present in large breeds, reduced in small)	Present (lateral recess, breed-dependent)	Often absent
Domestic cat (*Felis catus*)	Present (moderate, smaller than large felids)	Present (narrow recess)	Present (small)
Spotted hyena (*Crocuta crocuta*)	Present (very large, for bone-crushing)	Present (moderate recess)	Present (small)

provided here. Similarly, CT studies on leopards, lions, and foxes emphasize cranial biomechanics or dental morphology, with less focus on facial bone articulations or crest development.[13] The present study's use of volume-rendered 3D reconstructions thus offers a novel perspective, enhancing the anatomical reference for badgers and supporting clinical applications, such as diagnosing cranial fractures or dental pathologies.

In conclusion, the volume-rendered 3D reconstructions reveal a complex cranial morphology in the European badger, characterized by a robust zygomatic arch, large infraorbital foramen, and prominent cranial crests. These features, when compared to other carnivores, highlight adaptations for mastication, sensory function, and structural support, driven by the badger's ecological niche. This study advances the anatomical understanding of mustelids and supports the application of CT imaging in veterinary diagnostics. The use of more modern imaging techniques and the investigation of differences in the structures of the head region in males and females are recommended for future studies.

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Conflict of Interest

The authors declare that they have no conflicts of interest.

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