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CT Anatomy of the Skull in Alborz Wild Sheep (*O. o. arkali* & *O. o. vigneii*)

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ABSTRACT

Understanding the anatomical structures of endangered wildlife species is a real help for veterinarians in this field. The aim of this study was to determine the anatomy of the skull of this sheep, which is phenotypically similar to deer. In this study, the skulls of 6 male Alborz wild sheep, all alive, were examined. The examinations were performed using computed tomographic (CT) scans and radiographic images. It also processed and named the extracted images using RadiAnt and Photoshop software. Morphometric studies performed on the skull of this breed showed that the length, width, and height of the skull of wild Alborz rams were 25.28 ± 0.99, 12.34 ± 1.00, and 13.30 ± 0.63 cm, respectively. Measuring the volume of the head and nasal cavity in this sheep shows a volume of 1636.33 ± 73.34 and 177.08 ± 10.46 cm^3. Also, the volume of the frontal and lacrimal sinuses, which were the largest and smallest sinuses in the skull of this breed, respectively, were 219.90 ± 8.92 and 4.37 ± 0.66 cm^3. Frontal, maxillary, and lacrimal sinuses were observed like other ruminants. Contrary to the Egyptian sheep, Saanen, and Markhoz goat, palatine and sphenoid sinuses were also observed in this wildlife. Also, unlike Egyptian sheep and like Sanan goats, Markhoz goats, and Ile de France sheep, ventral conchal sinus was observed in this breed. Due to the study, CT scan and radiographic anatomy are important to investigate the characteristic features of the paranasal sinuses as well as their relations and communications with the other cavities in the head region of the Alborz wild sheep. Also, these features were very important prerequisites for diagnosing pathological conditions and clinical interference in the head region.

Introduction

Sheep and goat family, Bovidae, belongs to even-toed ungulates order, Artiodactyla, so their body characteristics, especially the bones of the skull can be similar to other ruminants. The Central Alborz wild sheep is a hybrid of the Urial ram with 58 chromosomes and the Armenian ram with 54 chromosomes. This ram is one of the largest hybrids mentioned. The sight, smell and hearing of these animals are very strong and they

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are aware of the danger of carnivores and fishermen.[1] Alborz wild sheep recorded in IUCN red list of threatened species, is distributed in relatively low populations in most of the protected areas of Tehran province (including Jajrud, Varjin, Lar, Koohsefid, and so forth). Based on the last winter census in 2014 in the province 7386 heads of this type have been counted in all areas under management.[2] Both males and females are horned in this species and have a deer-like appearance. So far, no study has been done on the anatomical features of this species, which is one of the endangered species in Iran.

The skull in all mammals consists of two parts of the calvarium, the part that contains the brain, and the viscerocranium, the facial portion of skull. The calvarium consists of several groups of bones divided according to their location: The bones that form the floor contain the basisphenoid and basioccipital bone. The parietal and nuchal wall of calvarium are composed of temporal and occipital bone, respectively. Also the roof where the brain is located includes frontal and parietal bone. The bones of the viscerocranium of the skull form the walls of the nasal cavities, the floors of which form the osseous roof of the oral cavity. The floor and the lateral walls of the oral cavity are completed by the lower jaw (mandible) and supported by the hyoid bone ventrally.[3] The shape and appearance of the head show many characteristics specific to breed, sex, and age, but they are for the most part of no great clinical interest. It is, however, important to note that the dorsal profile of the skull, unlike that of adult cattle, is domed over the cranial cavity and slopes caudally toward the nuchal plane; this feature is commonly masked by the location and size of the horns.[4]

Regarding the complexity of the head and due to the presence of numerous overlying structures, the radiographic evaluation of the head is slightly difficult. In the last several years, cross-sectional imaging techniques such as computed tomography (CT), magnetic resonance imaging (MRI), and ultrasonography have become more readily available. Such techniques have greatly simplified dentification of abnormalities in the head of animals.[5] CT scan is one of the non-invasive techniques that uses X-ray beam to give a sectional view of the body without superimpositioning of adjacent organs. In this way, valuable information is provided from different parts of the body with minimal invasion. In head CT scan, useful information is obtained by providing accurate cross-sectional images of the nasal cavity, paranasal sinuses and brain cavity. Also, CT scan provides a higher level of soft tissue contrast than radiographic findings, and will gives us the reconstructed images of the area in question at different levels. CT scan is an applied method for detecting spatial and transient lesions and a suitable method for choosing surgical approaches. Therefor for properly interpret the lesions, knowing the normal anatomy is essential.[6-8] Surveys on the sinuses and the upper respiratory tract can also help us better understanding respiratory disorders. In an investigation on the sheep inner ear, it was used as an animal model for the morphometry of the human ear by CT scan. According to the results, 10 of 15 structures of the inner ear of the sheep are similar to human's.[9] The advantage of CT scan as a biomechanical indicator is to demonstrate changes in skull of goat, *Capra hircus L*., studied.[10]

The most prominent advantage of these techniques is that anatomical structures can be investigated in live animals. Diagnostic imaging techniques are very suitable for anatomical studies of the coelomic cavity organs of animals such as turtles that are difficult to access, and methods such as CT scans have been used for these studies.[11,12] In addition, other methods, such as ultrasonography, have been used to study the anatomy of the heart structure in sturgeons.[13,14]

The aim of this study is to get comprehensive information about the nasal cavity and paranasal sinuses by CT scan and provide practical atlas for diagnostic imaging of the skull of Alborz Wildsheep (*O. o. arkali* & *O. o. vigneii*). In this study, we also attempt to compare the structures of the head, especially the paranasal sinuses of this breed, with other studies performed on Egyptian native sheep[15], Saanen goat[16] and Ile de France sheep.[17]

Materials and Methods

Samples and Preparation of Materials

At first the health total 6 male samples, which were mature in term of age, status was confirmed by clinical examination and the absence of bone deformities, which could be a sign of metabolic bone disease (MBD), was noted. six male sheep with an average age of 2.5 years old and weight of 50-55 kg were used in this study. CT of sheep head requires general anesthesia. The anesthetic plane follows by using a combination of ketamine at a dose of 2-5 mg/kg of body weight and diazepam at a dose of 0.1-0.2 mg/kg of body weight intravenously.[18]

CT Examination

Each sheep was placed in lateral position on the table. All CT scans were obtained by two detector scanners (Siemens somatom spirit dual sclice). The scanning parameters were as follow: rotation time, 1 s; slice thickness, 1 mm; reconstruction interval, 0.5–1 mm; pitch, 1; X-ray tube potential, 100-110 kilovolts of peak (kVp); and X-ray tube current, 140 mAs. The scanned images were started at the tip of the nose and covered the entire head to 2nd cervical vertebrae. Images were reconstructed with Syngo MMWP VE40A software in 2D sagittal and frontal planes. Both window width (WW) and window level (WL) were adjusted for skeletal structures (bone window). The obtained CT scan images were assessed in three orthogonal transverse, longitudinal and sagittal views as well as three-dimensional rendering reconstruction using bone and skin pattern.

Radiographic Examination

After CT examination, the sheep were taken to the radiographic room. Lateral (L) and DorsoVentral (DV) radiographs were taken using 100 cm focus film distance with 50 mA, 0.1 second, 70-75 kVp for lateral, and 75-80 kVp for DV radiographs and grid.

Analyzes

The morphometry of the skull of this sheep was studied using RadiAnt application. The measurement are shown in Figures 1 and 2. Volumetric calculations performed on the paranasal sinuses and nasal cavity of this breed were performed using RadiAnt software. To determine the volume of each structure, we first measure the area of each section with the close polygon tool and after summing the measured area in each section, we multiply it by the distance between the sections. This method is a semi-automatic method and unlike the cavalier method where the surface was calculated manually, it is obtained automatically by the software. Also, in order to increase the accuracy of the measurements, the average of the volume of each structure in the three views of transverse, longitudinal and sagittal has been announced. It should be noted that the measured sinuses (including cornual, maxillary, palatine, lacrimal, sphenoid, and conchal sinuses) volume are only in the right half of the skull. The volumetric measurements were recorded for each sheep separately and they were analysed by SPSS 2022 software and a paired sample t-test ($p \le 0.05$).

Gross Anatomical Study

For this part of the study, the skulls of 5 dead sheep (five adult males that had died in the past 5 years and were brought to our department) were collected and isolated, and no sheep were killed for this study. After separating the head of the specimens, the skin and unnecessary tissues were removed. All the osseous structures were macerated using the mealworm method (*Tenebrio molitor*) for 1 week (maintaining a

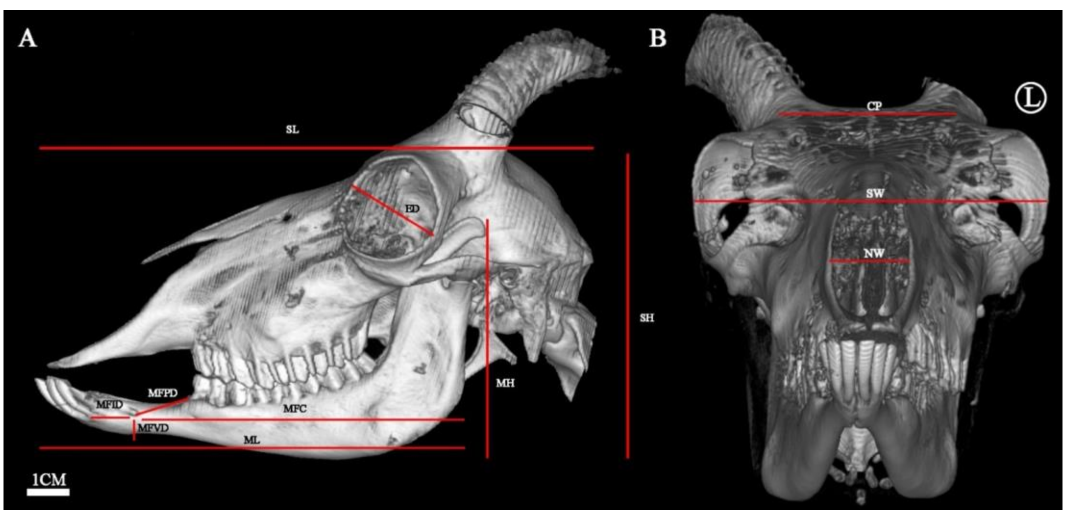

Figure 1. 3D reconstruction (osseous-shaped-vp) in the Alborz wild sheep. **(A)** lateral view, **(B)** cranial view. morphometric parameters of the head. Skull Height (SH), Skull length (SL), Skull Width (SW), Eye ball Diameter (ED), Nasal cavity Width in the cranial part (NW), Cornoal Process distance (CP), Mandibular Height (MH), Mandibular Length (ML), Distance from the Mental Foramen to the most Lateral incisive tooth (MFID), Distance from the Mental Foramen to the cranial margin of the first Premolar tooth (MFPD), Distance from the Mental Foramen to the Ventral margin of the mandibular body (MFVD), Distance from the Caudal margin of the Mandibular ramus to the mental foramen (MFC).

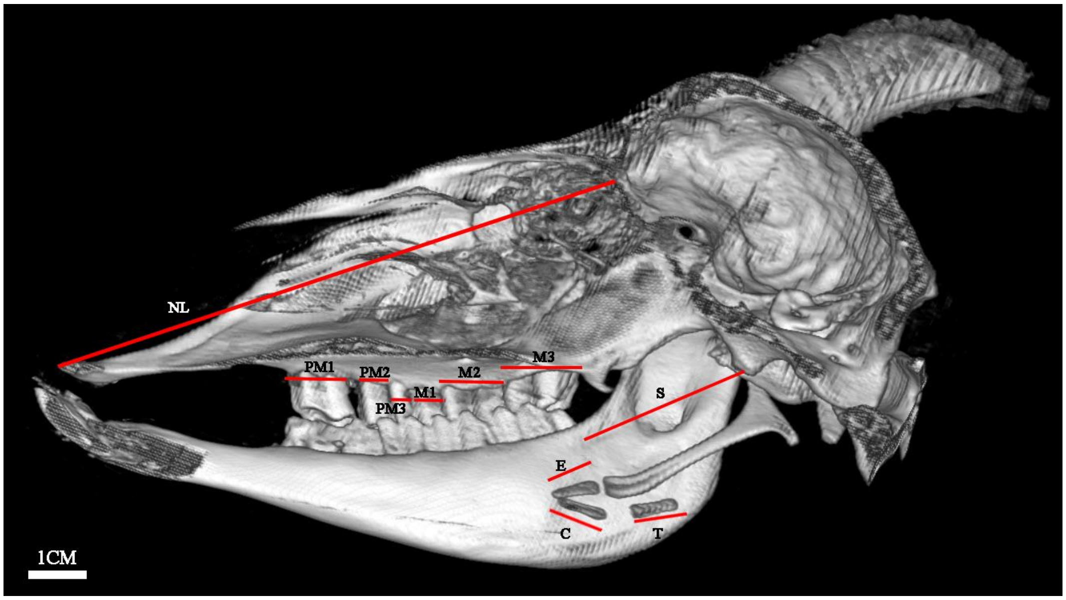

Figure 2. 3D reconstruction (osseous-shaped-vp) in the Alborz wild sheep. Medial view of sagittal section. morphometric parameters of tooth and hyoid bone. Nasal cavity Length (NL), Incisor 1 length (I1), Premolar 1 length (PM1), Premolar 2 length (PM2), Premolar 3 length (PM3), Molar 1 length (M1), Molar 2 length (M2), Molar 3 length (M3), Stylohyoid length (S), Epihyoid length (E), Ceratohyoid length (C), Thyrohyoid length (T).

temperature of 21° C and relative humidity of 70% to provide an optimum medium for insects), and to separate the bones pieces, the conventional process of bone separation including soft tissue separation, boiling, degreasing, and bleaching has been used. Before boiling the samples, the bones removed from the soft tissue were placed in cold water for 24 hours and a small amount (much less than 10%) of household ammonia was added to the water. 10% hydrogen peroxide was used for bleaching. Due to the large volume of samples and the high cost of common solutions for the degreasing stage, super gasoline was used for this stage.[19]

Results

Calvarium

At first glance, the skull of this male wild sheep has horns and looks long. It also has large, protruding eyes from the cranium cavity. The horns are symmetrically located at the dorso-caudal part of the frontal bone and are angled to the back of the skull. As mentioned earlier, the skull is divided into two parts, calvarium and viscerocranium, which will be explained separately in the following.

Roof of Calvarium. The roof of this part, which also forms the brain wall, is composed of various structures. These structures are responsible for protecting the brain and are therefore all bony. These bones, which include the frontal and parietal bones, have cavities to reduce the weight of the head and protect the brain.

The frontal bone is in posterior part of the nasal bone and forms the cranial part of the roof of the brain (Figures 3/39, 4/26, and 5/10). This bone is at level of the last Asian tooth and continues to the base of the horn (Figures 6/2 and 9/27). There is a depression in the middle of this bone that almost divides it into two parts (Figure 3/33). There is also this depression inside the frontal sinus, which will be discussed below.

The supra-orbital foramen, which is located in the dorsal part of the mid frontal bone, is paired and forms the output section of the supra-orbital canal. As shown in Figures 3/32 and 12/3, this foramen is located in the middle of the frontal sinus.

The parietal bone forms the caudal part of the roof of the skull, as well as a small part of the protective structures of the brain (Figures 5/13 and 6/3). As shown in Figure 12/21, the parietal bone is the small bone between the frontal and interparietal bone bones.

Parietal Part of Calvarium. The lateral part of calvarium includes the temporal bone. Also present in this section are the external structures that make up the ear.

The temporal bone protects both sides of the brain and, as you can see in Figure 9/21, also plays a direct role in the formation of temporo-mandibular joint. The range of this bone is from the back of the eyeball to the beginning of the occipital bone.

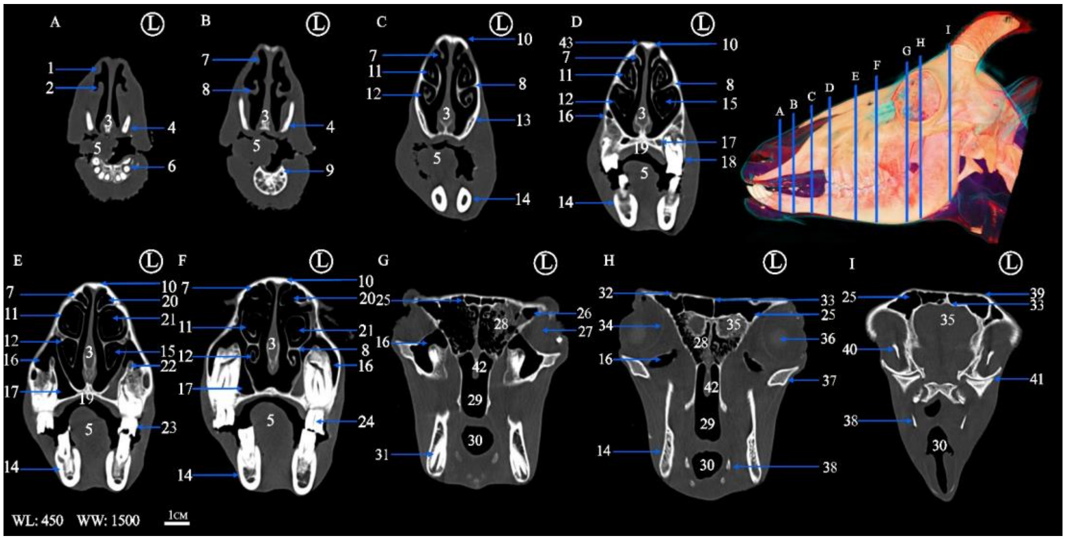

Figure 3. 2D CT scan images (transverse view – bone window) in the Alborz wild sheep. **(A)** transverse section at level of incisive tooth; **(B)** transverse section at level of diastema; **(C)** transverse section at level of 1 cm cranial to the pm1; **(D)** transverse section at level of pm1; **(E)** transverse section at level of pm3; **(F)** transverse section at level of m1; **(G)** transverse section at level of rostral part of eye; **(H)** transverse section at level of eye; **(I)** transverse section at level of temporomandibular joint (TMJ). 1, Straight fold of dorsal nasal concha; 2, alar fold of ventral nasal concha; 3, nasal septum; 4, nasal process of incisive bone; 5, tongue; 6, incisive teeth; 7, dorsal nasal concha; 8, ventral nasal concha; 9, diastema; 10, nasal bone; 11, dorsal lamella of ventral nasal concha; 12, ventral lamella of ventral nasal concha; 13, maxillary bone; 14, mandible; 15, ventral part of ventral conchal sinus; 16, maxillary sinus; 17, palatine sinus; 18, first premolar tooth (pm1); 19, hard palate; 20, dorsal conchal sinus; 21, dorsal part of ventral conchal sinus; 22, infra–orbital canal; 23, pm3; 24, first molar tooth (m1); 25, frontal sinus; 26, lacrimal sinus; 27, eye ball; 28, ethmoidal labyrinth; 29, choanae; 30, larynx; 31, root of m3; 32, supra-orbital foramen; 33, inter-frontal septum; 34, retina; 35, brain; 36, lens; 37, zygomatic arch; 38, stylohyoid; 39, frontal bone; 40, coronoid process of mandible; 41; TMJ; 42, vomer; 43, nasal fissure.

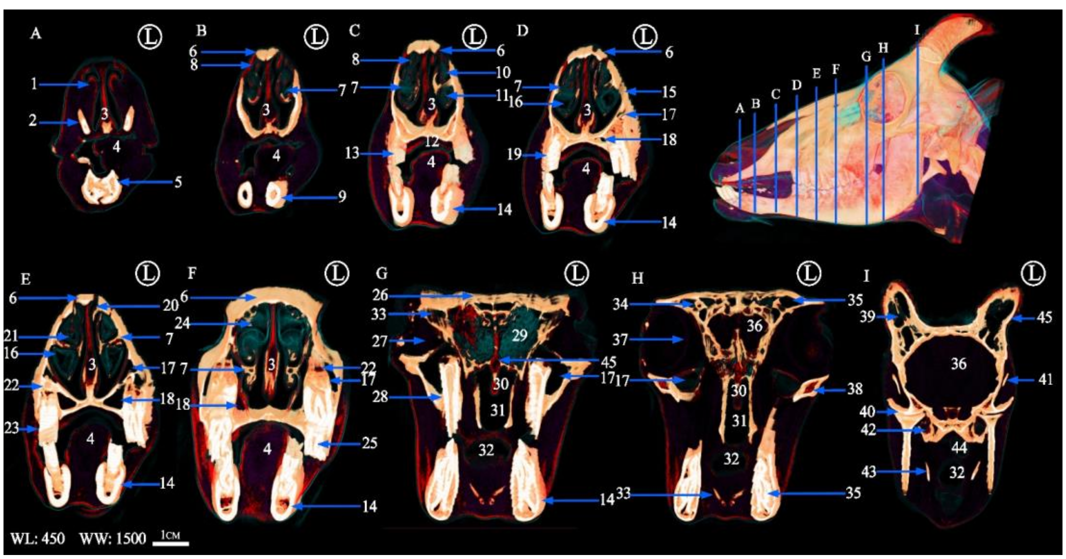

Figure 4. 3D CT scan images (transverse view – bone & skin view) in the Alborz wild sheep. **(A)** transverse section at level of incisive tooth; **(B)** transverse section at level of diastema; **(C)** transverse section at level of pm1; **(D)** transverse section at level of pm2; **(E)** transverse section at level of pm3; **(F)** transverse section at level of m1; **(G)** transverse section at level of rostral part of eye; **(H)** transverse section at level of eye; **(I)** transverse section at level of TMJ. 1, Straight fold of dorsal nasal concha; 2, nasal process of incisive bone; 3, nasal septum; 4, tongue; 5, incisive bone; 6, nasal bone; 7, dorsal nasal concha; 8, ventral nasal concha; 9, diastema; 10, dorsal lamella of ventral nasal concha; 11, ventral lamella of ventral nasal concha; 12, hard palate; 13, pm1; 14, mandible; 15, maxillary bone; 16, ventral part of ventral conchal sinus; 17, maxillary sinus; 18, palatine sinus; 19, pm2; 20, dorsal conchal sinus; 21, dorsal part of ventral conchal sinus; 22, infra–orbital canal; 23, pm3; 24, middle conchal sinus; 25, m1; 26, frontal bone; 27, eye ball; 28, m3; 29, ethmoidal labyrinth; 30, vomer; 31, choanae; 32, larynx; 33, hyoid bone; 34, supra-orbital canal; 35, frontal sinus; 36, brain; 37, retina; 38, zygomatic arch; 39, cornoal sinus; 40, TMJ; 41, coronoid process of mandible; 42, tympanic bulla; 43, stylohyoid; 44, trachea; 45, sphenoid sinus.

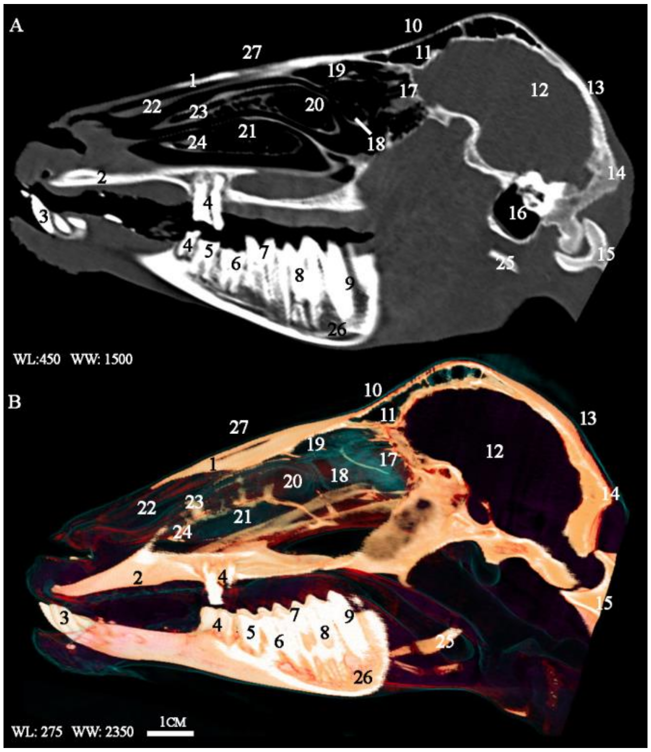

Figure 5. CT scan images (sagittal view) in the Alborz wild sheep. **(A)** 2D bone view, **(B)** 3D bone & skin view. 1, Nasal bone; 2, incisive bone; 3, incisive tooth; 4, pm1; 5, pm2; 6, pm3; 7, m1; 8, m2; 9, m3; 10, frontal bone; 11, frontal sinus; 12, brain; 13, parietal bone; 14, squamous part of occipital; 15, atlas; 16, tympanic bulla; 17, Ethmoidal labyrinth; 18, middle conchal sinus; 19, dorsal conchal sinus; 20, dorsal part of ventral conchal sinus; 21, ventral part of ventral conchal sinus; 22, dorsal nasal concha; 23, dorsal lamella of ventral nasal concha; 24, ventral lamella of ventral nasal concha; 25, hyoid; 26, mandible; 27, nasal fissure.

The external acoustic meatus connects the outer part of the ear, which is the eardrum, to the middle part of the ear, which includes the ossicles, and finally the inner part of the ear (Figures 6/11, 8/5, 9/24, and 10/11).

Nuchal Part of Calvarium. The nuchal part of calvarium includes the occipital bone. This bone, which connects the spine to the skull, is made up of different parts, some of which extend to the floor of the calvarium and form several structures (Figures 5/14, 6/4, and 8/8). One of the most important parts of this bone, as you can see in Figure 9/25, is the occipital condyles, which attach the atlas to the skull. These condyles are conjugate and symmetrically on either side of the occipital bone. Also, the magnum foramen, which is located in the middle of the occipital bone, connects the spinal canal and the fourth ventricle of the brain (Figure 10/10). The spinal cord passes through the middle of the magnum foramen, and the angle that forms between the atlas vertebra and the skull

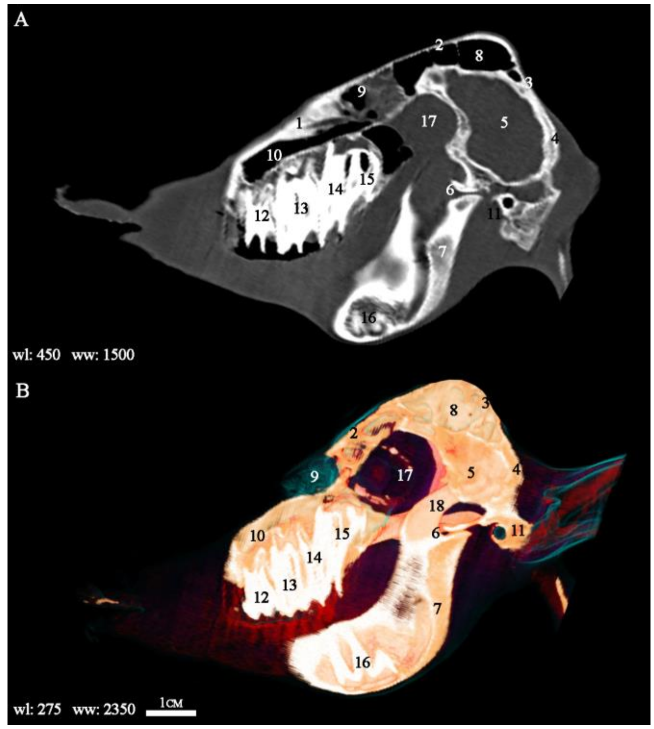

Figure 6. CT scan images (sagittal view) in the Alborz wild sheep at level of TMJ. **(A)** 2D bone view, **(B)** 3D bone & skin view. 1, Maxillary bone; 2, frontal bone; 3, parietal bone; 4, squamous part of occipital; 5, brain; 6, TMJ; 7, mandible; 8, frontal sinus; 9, lacrimal sinus; 10, maxillary sinus; 11, external acoustic meatus; 12, pm3; 13, m1; 14, m2; 15, m3; 16, root of lower m3; 17, eye ball; 18, coronoid process of mandible.

when the head is flex ventrally; is where the contrast agents or anesthetic is injected, or the cerebrospinal fluid (CSF) drain.

Paranasal Sinuses

As mentioned earlier, the presence of these hollow, air-filled bone structures, in addition to lightening the weight of the skull, protects the head from impact. Also, due to the proximity of some of these sinuses to infected structures such as teeth, it is necessary to examine these sinuses more thoroughly and completely. The paranasal sinuses in Alborz wild sheep is composed of maxillary, frontal, palatine, lacrimal and sphenoid sinuses. The location of each of the paranasal sinuses compared to the maxillary teeth is presented in Table 1 along with the corresponding Figure(s).

Frontal Sinus. Frontal sinus was the largest sinus which was started from the end of the third molar tooth continued up to roof of brain and end in Cornual diverticulum of caudal frontal sinus (Figure 9/34). The frontal sinus is divided by inter-frontal septum into right and left from beginning to end (Figures 3/25, 4/35, 5/11, 6/8, 9/32, and 11/5).

Table1. The location of nasal and paranasal sinuses according to the maxillary teeth.

Dental Nu. / Nasal & paranasal sinuse	Pm¹	Pm²	Pm³	M¹	M²	M³	POr	Figure(s)
Frontal sinus								3/25, 4/35, 5/11, 6/8, 9/32 and 11/5
Maxillary sinus								3/16, 4/17, 6/10, 8/1, 8/2, 9/30 and 10/6
Palatine sinus								3/17, 4/18, 8/10, 9/4 and 10/2
Lacrimal sinus								3/26, 6/9, 9/15 and 9/31
Sphenoid sinus								4/45
Dorsal conchal sinus								3/20, 4/20, 5/19 and 11/1
Middle conchal sinus								4/24, 5/18 and 11/3
Ventral conchal sinus								3/15, 3/21, 4/16, 4/21, 5/20, 5/21 and 11/2

Pm1; first maxillary premolar tooth, Pm2; second maxillary premolar tooth, Pm3; third maxillary premolar tooth, M1; first maxillary molar tooth, M2; second maxillary molar tooth, M3; third maxillary molar tooth, POr; post orbital rejoins.

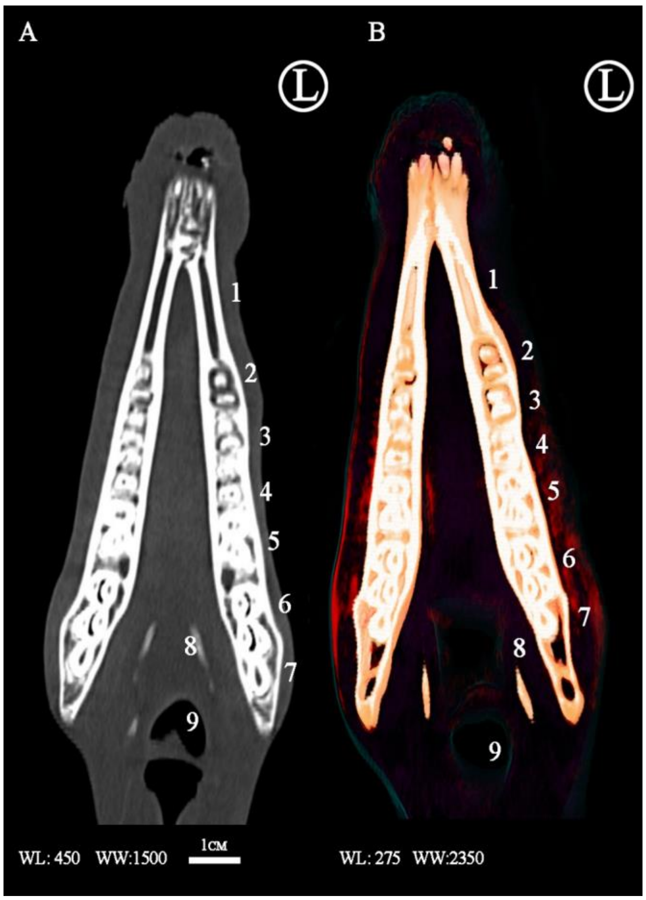

Figure 7. CT scan images (coronal view) in the Alborz wild sheep at level mandibular teeth. **(A)** 2D bone view, **(B)** 3D bone & skin view. 1, diastema 2, pm1; 3, pm2; 4, pm3; 5, m1; 6, m2; 7, m3; 8, hyoid bone; 9, trachea.

The supra–orbital canal has passed through the middle of this sinus and ends in the last third of the eye ball (Figure 4/34).

Maxillary Sinus. Maxillary sinus started at the posterior part of third premolar tooth and continued up to the caudal and ventral of post avleolar region. Maxillary sinus continues parallel to nasal cavity and it was separated by a thin wall from ventral nasal concha (Figures 3/16, 4/17, 6/10, 8/1, 8/2, 9/30, and 10/6).

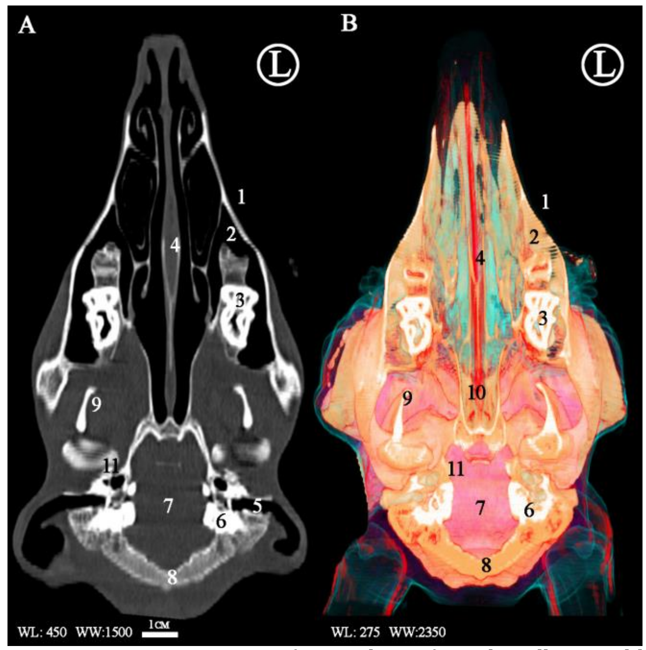

Figure 8. CT scan images (coronal view) in the Alborz wild sheep at level of external acoustic meatus. **(A)** 2D bone view, **(B)** 3D bone & skin view. 1, maxillary sinus; 2, maxillary sinus; 3, m3; 4, nasal septum; 5, external acoustic meatus; 6, tympanic bulla; 7, brain; 8, squamous part of occipital; 9, coronoid process of mandible; 10, palatine bone; 11, internal acoustic meatus.

The foramen of infra – orbital canal is also passes through this sinus and it divides the sinus into medial and lateral chambers. The root of all cheek teeth was separated from this sinus with a thin bone wall and this close connection makes the maxillary sinus recurrent in dental sinusitis (3/22, 4/22, and 9/14).

Palatine Sinus. Palatine sinus was located between the level of middle part of second premolar tooth to last molar one. This sinus was at the ventromedial part of maxillary sinus and it has straight connection with it at all parts (Figures 3/17, 4/18, 8/10, 9/4, and 10/2). Also, this sinus like maxillary sinus has close connection to root of teeth and it makes them at danger of dental sinusitis.

Lacrimal Sinus. lacrimal sinus started at the level of end of last molar tooth. (Figures 3/26, 6/9, and 9/31). Lacrimal sinus was more dorsally and medial to nasolacrimal duct and its end part was more rostrally in comparison with maxillary sinus (Figure 9/15).

Sphenoid Sinus. The sphenoid sinus is the air-filled space inside the sphenoid bone at the floor of the skull. This sinus is not developed and is next to optic nerves in terms of location (Figure 4/45).

Viscerocranium

This part of the skull consists of two cavities with bony supporting structures. The nasal cavity and the oral cavity are separated by a hard palate at the cranial of the skull and a soft palate at the end (Figures 3/19 and 4/12). These two cavities meet at the end of the viscerocranium. The nasal, maxillary, palatine, mandible and zygomatic bones are the protective structures of this part of the skull. Macroscopic examination of the skeletal structures of the skull as well as CT scans obtained from the skulls of Alborz wild sheep indicate the presence of a fissure in nasal the nasal bone (Figure 12/10). This fissure was located on the dorsal nasal meatus but it had not communication with nasal cavity (Figures 3/43 and 5/27).

Infra-orbital canal opens onto the maxilla at the infra-orbital foramen and continued up to third molar tooth (3/22, 4/22, 9/14, and 12/4). Infra-orbital canal started from more caudally, ventrally and medially in comparison with nasolacrimal duct.

Nasal Cavity. The nasal cavity extends from the nostrils to the level of the eyes at the ethmoidal labyrinth (Figures 3/28, 4/29, 5/17, and 9/19). The nasal cavity is divided into two halves by the nasal septum (Figures 3/3, ¾, and 4/8).

Nasal Concha and Folds. Straight fold started from the beginning of palatine fissure and was as far as the nasal bones continued (Figures 3/1 and 4/1). Basal fold began before the anterior edge of incisive bone and continued up to the alar fold. Alar fold started at the anterior edge of incisive bone and continued up to the middle portion of palatine fissure (Figure 3/2).

Dorsal nasal concha, which is the continuation of straight fold, is located in the middle of the nasal cavity and continues to ethmoidal labyrinth (Figures 3/7, 4/7, 5/22, and 11/11). Middle nasal concha was followed with ethmoid concha at the level of secondary molar tooth up to the postalveolar region. Also ventral nasal concha is created by alar and basal fold which gives this fold a spiral appearance (Figures 3/8, 4/8, and 11/13). ventral nasal concha in most parts, was in the form of dorsal and ventral spiral of ventral nasal concha (Figures 3/11 and 12, 4/10, and 11, 5/23 and 24, and 11/12).

Conchal Sinus. The conchal sinuses, in the Alborz wild sheep, are divided into three sinuses, dorsal, middle and ventral conchal sinus. each of which occupies part of the nasal cavity. The location of each of the nasal sinuses compared to the maxillary teeth is presented in Table 1 along with the corresponding Figure(s).

Dorsal conchal sinus is located in the middle of dorsal nasal concha, which was started at the level of first molar tooth and continued to end of third molar tooth (Figures 3/20, 4/20, 5/19, and 11/1). Middle conchal sinus started at level of secondary molar tooth and continued down to the dorsal conchal sinus to ethmoidal labyrinth (Figures 4/24, 5/18, and 11/3). Ventral conchal sinus is divided into two parts. The ventral part of ventral conchal sinus was began at level of first premolar tooth to secondary molar tooth, but the dorsal one was from second premolar tooth to third molar tooth (Figures 3/15, 3/21, 4/16, 4/21, 5/20, 5/21, and 11/2).

Oral Cavity. The oral cavity consists of teeth, tongue, throat, pharynx, larynx and hyoid apparatus. In this sheep, there are 4 incisive teeth in the lower two halves and two upper halves do not have incisive teeth. There are also 3 premolar teeth and 3 molar teeth in each upper and lower half of the jaw.

The pharynx is the common cavity through which both air and ingested material pass. It connects the oral cavity with the oesophagus and the nasal cavity with the larnyx. The soft palate at the end of the nasal and oral cavities continued in this breed at level of third molar tooth to larynx. The larynx is a bilaterally symmetrical, tube-shaped musculocartilagenous organ, that connects the pharynx to the trachea (Figures 3/30 and 4/32).

Hyoid Apparatus. In Alborz wild sheep, hyoid apparatus is a structure that exists symmetrically on both sides of the trachea and consists of 4 pairs of bones with a lingual process.A substantial median lingual process pro jects from the transverse basihyoid into the root of the tongue. From each end of the basihyoid extend the thyrohyoids caudally to the thyroid cartilage of the larynx (Figures 3/38, 4/43, 9/35, and 11/10). Stylohyoid is the latter joints which connects the hyoid apparatus to the styloid process of the tympanic part of the temporal bone (Figures 4/33,

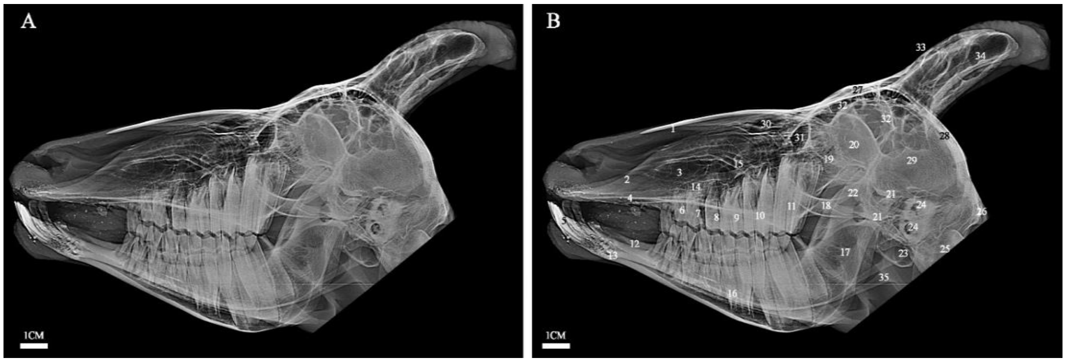

Figure 9. Radiograph images of skull (Lateral view) in the Alborz wild sheep. **(A)** Image without number; **(B)** numeral image.1, nasal bone; 2, incisive bone; 3, maxillary bone; 4, palatine process of incisive bone; 5, incisive tooth; 6, first premolar tooth (pm1); 7, pm2; 8, pm3; 9, first molar tooth (m1); 10, m2; 11, m3; 12, diastema; 13, mental foramen; 14, infra–orbital canal; 15, nasolacrimal duct; 16, ventral border of mandible; 17, mandible; 18, zygomatic arch; 19, ethmoidal labyrinth; 20, eye ball; 21, TMJ; 22, coronoid process of mandible; 23, tympanic bulla; 24, external acoustic meatus; 25, atlas; 26, squamous part of occipital; 27, frontal bone; 28, parietal bone; 29, lateral wall of neurocranium; 30, maxillary sinus; 31, lacrimal sinus; 32, frontal sinus; 33, horn; 34, Cornual diverticulum of caudal frontal sinus; 35, stylohyoid.

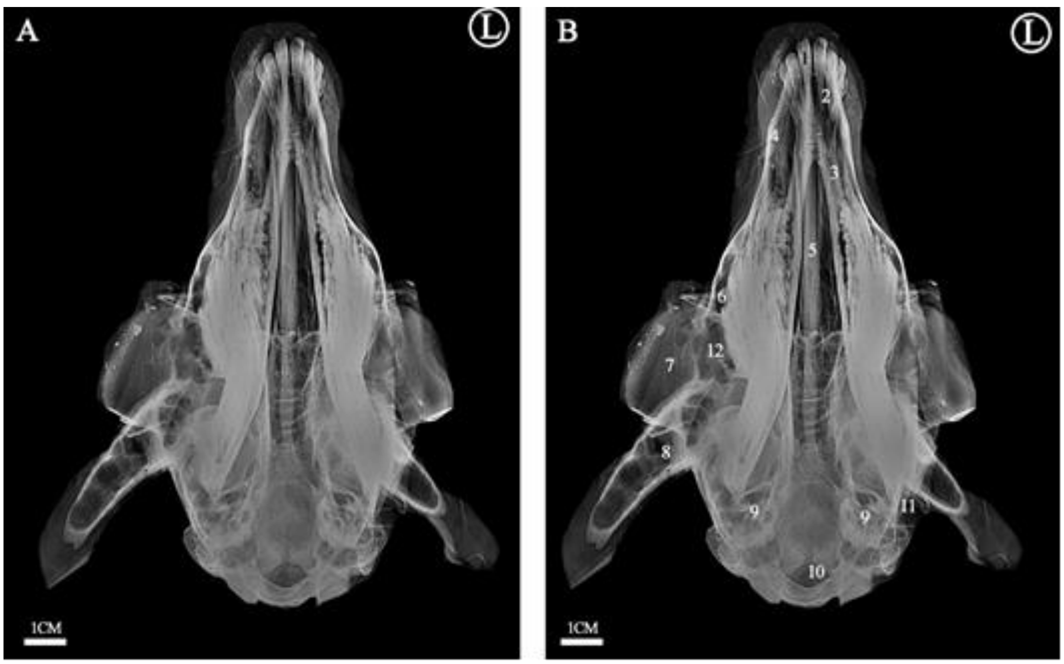

Figure 10. Radiograph images of skull (DorsoVentral (DV) view) in the Alborz wild sheep. **(A)** Image without number; **(B)** numeral image.1, Incisive tooth; 2, palatine fissure; 3, diastema; 4, maxilla; 5, vomer; 6, maxillary sinus; 7, eye ball; 8, horn; 9, tympanic bulla; 10, foramen magnum; 11, external acoustic meatus.

5/25, 8/7, and 11/8). The latter joins the hyoid apparatus to the head by forming a syndesmosis with the styloid process of the tympanic part of the temporal bone.

Mandible. The mandible is a paired bone, which is firmly united rostrally by the fibrous tissue of the mandibular symphysis. The body of each mandible extends to form the angular process caudally. The body of the mandible can be subdivided into a rostral part, that contains the incisor teeth and a caudal part, that contains the cheek teeth (Figures 3/14, 4/14, 5/26, 6/7, and 9/17). Coronoid process of mandible, which is the tallest part of the mandible, passes through zygomatic process of temporal bone in this sheep and is in caudo-dorsal position from temporomandibular joint (Figures 3/40, 4/41, 6/8, 8/9, and 9/22).

The temporomandibular joint (TMJ) is the synovial joint between the mandibular ramus and the squamous part of the temporal bone (Figures 3/41, 4/40, 6/6, 9/21, and 12/16).

Interalveolar space or diastema was also observed in this sheep between last incisive and first premolar teeth of mandible (Figures 3/9, 4/9, 7/1, 9/12, and 10/3).

Morphometric Study

The results of morphometric examination of Alborz wild sheep skulls can be seen in Tables 2 to 5. Also, the factors used in morphometric studies are shown in Figures 1 and 2. The average length, width and height of the sheep's skull were 25.28 ± 0.99, 12.34 ± 1.00 and 13.30 ± 0.63 cm, respectively. Also, the length and width of the nasal cavity were calculated as 15.02 ± 0.74 and 2.65 ± 0.59 cm on average. The average diameter of the eyeball in this sheep was 4.41 ± 0.56 cm. The diameter of the horn in the male of this sheep was measured on average 5.32 ± 0.80 cm; It should be noted that no difference was observed between the diameter of the left and right horns.

Morphometric examinations of the mandible showed that the bone was 18.55 ± 0.48 cm long on average. Also, the average height of this bone from the lowest part to coronoid process was calculated to be 10.58 ± 0.52 cm. The average distance between the last incisive tooth to the mental foramen (MFID) and the first premolar tooth to the mental foramen (MFPD) were calculated as 2.03 ± 0.60 and 2.52 ± 0.66 cm, respectively.

The hyoid apparatus consists of 4 pairs of bones, the tallest and smallest of which are stylohyoid and epihyoid, are 5.66 ± 0.45 and 1.14 ± 0.47 cm long on average, respectively. Also, the average lengths of cerato and thyrohyoid were 1.54 ± 0.42 and 1.33 ± 0.44 cm, respectively.

Measurement of male teeth of Alborz wild sheep showed that the largest teeth of this sheep in terms of length were the last molar teeth with the average length of 2.05 ± 0.39 cm and the smallest teeth were the incisive teeth with a length of 0.67 ± 0.33 cm. Also, the length of the first molar and premolar teeth was 1.29 ± 0.26 and 0.97 ± 0.18 cm, respectively, and averaged.

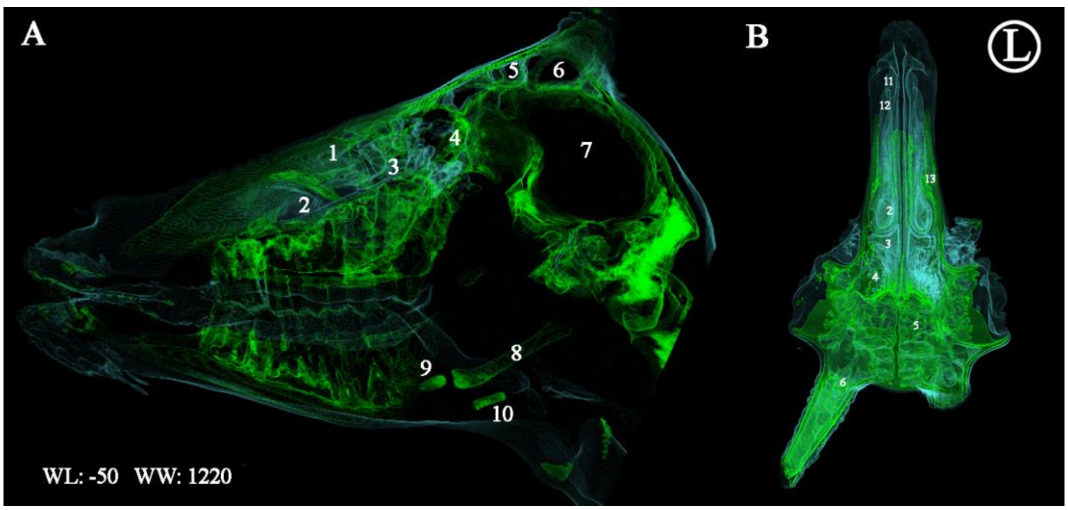

Figure 11. 3D CT scan images of skull in the Alborz wild sheep. Air way view. (A) Medial view of sagittal section; (B) dorsal view of cornual section. 1, Dorsal conchal sinus; 2, ventral conchal sinus; 3, middle conchal sinus; 4, ethmoidal labyrinth; 5, frontal sinus; 6, Cornual diverticulum of caudal frontal sinus; 7, brain; 8, stylohyoid; 9, ceratohyoid; 10, thyrohyoid; 11, dorsal nasal concha; 12, ventral nasal concha; 13, maxillary sinus.

Figure 12. (A) Dorsal view and (B) lateral view of skull of Alborz wild sheep. 1, Frontal bome; 2, nasal bone; 3, supra-orbital foramen; 4, infra-orbital foramen; 5, maxillary bone; 6, zygomatic bone; 7, lacrimal bone; 8, eye ball; 9, inter–frontal septum; 10, nasal fissure; 11, horn; 12, palatine process of incisive bone; 13, incisive tooth; 14, mental foramen; 15, ramous of mandible; 16, TMJ; 17, coronoid process of mandible; 18, optic nerve; 19, external acoustic opening; 20, paracondyloid process; 21, parietal bone; 22, interparietal bone.

Table2. Morphometric results of head (unit of measurement is cm) in the skull of Alborz wild sheep.

No	SH	SL	SW	NL	ED	NW	CP
M1	13.77	25.26	12.28	15.51	4.41	2.89	5.38
M2	14.22	26.06	13.21	16.33	5.05	3.04	6.18
M3	12.87	24.66	11.87	14.25	3.77	2.22	4.91
M4	13.51	24.33	11.51	14.41	5.22	3.03	4.74
M5	13.24	27.06	14.05	15.23	4.33	3.22	6.53
M6	12.23	24.34	11.13	14.44	3.73	1.54	4.22
Mean ± SD	13.30 ± 0.63	25.28 ± 0.99	12.34 ± 1.00	15.02 ± 0.74	4.41 ± 0.56	2.65 ± 0.59	5.32 ± 0.80

Skull height (SH), skull length (SL), skull width (SW), nasal cavity length (NL), eye ball diameter (ED), nasal cavity width in the cranial part (NW), cornoal process distance (CP).

Table3. Morphometric results of mandible (unit of measurement is cm) in the skull of Alborz wild sheep.

No	MH	ML	MFID	MFPD	MFVD	MFC
M1	10.74	18.74	2.26	2.62	0.95	14.05
M2	11.33	19.11	3.21	3.41	1.12	15.34
M3	9.87	17.81	1.22	1.43	0.74	13.66
M4	10.33	18.42	1.96	3.02	1.15	13.84
M5	11.14	19.11	1.86	2.75	0.81	14.23
M6	10.12	18.15	1.72	1.92	0.57	13.76
Mean ± SD	10.58 ± 0.52	18.55 ± 0.48	2.03 ± 0.60	2.52 ± 0.66	0.89 ± 0.20	14.14 ± 0.56

Mandibular height (MH), mandibular length (ML), distance from the mental foramen to the most lateral incisive tooth (MFID), distance from the mental foramen to the cranial margin of the first premolar tooth (MFPD), distance from the mental foramen to the ventral margin of the mandibular body (MFVD), distance from the caudal margin of the mandibular ramus to the mental foramen (MFC).

Table4. Morphometric results of hyoid bone (unit of measurement is cm) in the skull of Alborz wild sheep.

No	S	E	C	T
M1	5.47	1.22	1.42	1.24
M2	6.25	2.11	2.31	2.22
M3	4.86	0.72	0.91	0.86
M4	5.54	1.13	1.57	1.34
M5	6.11	0.94	1.32	0.92
M6	5.76	0.72	1.72	1.43
Mean ± SD	5.66 ± 0.45	1.14 ± 0.47	1.54 ± 0.42	1.33 ± 0.44

Stylohyoid length (S), epihyoid length (E), ceratohyoid length (C), thyrohyoid length (T).

Table5. Morphometric results of teeth (unit of measurement is cm) in the skull of Alborz wild sheep.

No	I_1	PM_1	PM_2	PM_3	M_1	M_2	M_3
M1	0.47	0.85	0.86	1.08	1.22	1.74	2.06
M2	1.27	1.15	1.22	1.92	1.82	2.33	2.88
M3	0.33	0.66	0.54	0.98	0.95	1.14	1.71
M4	0.55	0.91	0.78	1.16	1.31	1.66	2.11
M5	1.07	1.12	0.89	0.81	1.13	1.91	1.71
M6	0.33	1.15	1.16	0.98	1.34	2.04	1.86
Mean ± SD	0.67 ± 0.33	0.97 ± 0.18	0.90 ± 0.22	1.15 ± 0.35	1.29 ± 0.26	1.80 ± 0.36	2.05 ± 0.39

Incisor 1 length (I1), premolar 1 length (PM1), premolar 2 length (PM2), premolar 3 length (PM3), molar 1 length (M1), molar 2 length (M2), molar 3 length (M3).

Table6. Volumetric results of head (unit of measurement is cm^3) in the skull of Alborz wild sheep.

No	HV	NCV	OCV	OrCV	MIEV	CerV	CerbV	BsV
M1	1619.36	176.68	145.25	87.65	7.56	223.69	135.87	46.61
M2	1721.22	188.45	162.21	96.12	8.26	231.11	131.72	41.11
M3	1512.34	155.11	122.54	61.32	5.21	219.55	125.41	39.45
M4	1623.13	181.22	155.43	91.25	8.36	228.19	137.77	47.77
M5	1729.42	181.87	151.33	91.25	8.26	222.11	122.55	42.21
M6	1612.56	179.18	155.44	77.15	8.11	233.65	127.57	44.23
Mean ± SD	1636.33 ± 73.34	177.08 ± 10.46	148.70 ± 12.75	84.12 ± 11.73	7.62 ± 1.11	226.38 ± 5.01	130.14 ± 5.47	43.56 ± 2.94

Head volume (HV), nasal cavity volume (NCV), oral cavity volume (OCV), orbital cavity volume in half skull (OrCV), middle and internal ear volume in half skull (MIEV), cerebral volume (CerV), cerebellar volume (CerbV), brainstem volume (BsV).

Table7. Volumetric results of sinuses (unit of measurement is cm^3) in the skull of Alborz wild sheep. The volume measured in each of cornoal, maxillary, palatine, lacrimal, sphenoid, dorsal and middle and ventral conchal sinus is on one side of the skull.

No	Frontal sinus	Cornual sinus	Maxillary sinus	Palatine sinus	Lacrimal sinus	Sphenoid sinus	Dorsal conchal sinus	Middle conchal sinus	Ventral conchal sinus
M1	217.81	262.23	188.95	54.27	4.14	12.12	22.77	18.54	25.41
M2	222.06	277.22	199.15	61.12	4.89	12.55	23.12	19.24	26.74
M3	205.55	202.32	158.14	44.34	3.11	11.23	21.51	17.24	24.04
M4	216.16	271.41	195.15	61.23	4.88	12.65	23.07	19.12	26.24
M5	235.71	288.41	191.11	61.54	5.04	13.22	23.05	19.11	26.68
M6	216.60	271.12	193.05	54.13	4.18	11.92	23.17	18.23	25.67
Mean ± SD	219.90 ± 8.92	262.11 ± 27.87	187.59 ± 13.55	56.10 ± 6.14	4.37 ± 0.66	12.28 ± 0.62	22.78 ± 0.58	18.58 ± 0.69	25.79 ± 1.05

Volumetric Study

The results of examining the volume of the skull of Alborz wild sheep, which is available in Table 6, indicate the average volume of 1636.33 ± 73.34 and 177.08 ± 10.46 cm^3 of the head and nasal cavity. Also, the volume of oral cavity, eyeball and inner and middle ear canals were calculated as 148.70 ± 12.75, 84.12 ± 11.73 and 7.62 ± 1.11 cm^3 on average, respectively. The average volume of cerebrum, cerebellum, and brainstem were 226.38 ± 5.01, 130.14 ± 5.47 and 43.56 ± 2.94 cm^3 in Alborz wild sheep, respectively.

According to the information in Table 7, the largest sinus in this breed of small ruminants was the frontal sinus with the average volume of 219.90 ± 8.92 cm^3 and the smallest sinus was the lacrimal sinus with the average volume of 4.37 ± 0.66 cm^3. The volume of maxillary, palatine and sphenoid sinuses was also 187.59 ± 13.55, 56.10 ± 6.14 and 12.28 ± 0.62 cm^3, respectively and averaged. Also, the sinuses of dorsal and middle conchal, which are located in the nasal cavity, were 22.78 ± 0.58 and 18.58 ± 0.69 cm^3 on average, respectively.

According to the results of the statistical analysis on the volume measurement data of different sinuses in the skull of Alborz wild sheep, the volume difference between the frontal and maxillary, frontal and palatine, frontal and lacrimal, frontal and dorsal conchal, sphenoid and maxillary sinuses and also between the sphenoid and the dorsal conchal sinus, was significant ($p \geq 0.05$).

Discussion

The study of animal skull anatomy using radiography has long been considered by researchers. [5] CT scan has also attracted the attention of anatomical scientists in recent years. Among the studies performed to identify the anatomical areas of the skull of animals, we can mention goat,[20,21] buffalo,[22] Rayini goat,[23] camel,[24] donkey (*Equus asinus*),[25] cattle,[26] Egyptian native sheep,[15] Saanen goat,[16] Barking deer and Sambar deer,[27] and Ile de France sheep.[17]

Identifying how diferent parts of the complex architecture of the head and its structures are interconnected has always been troublesome. Due to the vicinity of air and bone in the nasal cavities, the nasal structures were easily identified in the CT images.[28]

The present study showed that Alborz wild sheep's head contained five paranasal sinuses, namely maxillary, frontal, palatine, sphenoid and lacrimal sinuses. Because the relevant clinical applications in correlation to the gross anatomy of the paranasal sinuses remain inadequate, especially in sheep, so, it is necessary to understand the definite position, extension and communication of these sinuses to improve the diagnosis of the upper respiratory tract disorders.[29,30] The palatine and sphenoidal sinuses were seen within the Alborz wild sheep's head. There is a variable status in different ruminant breeds concerning the palatine and sphenoidal sinuses. The palatine sinus which was previously identified in buffalo,[22] Iraqi local goat,[31] Rayini goat,[23] sheep,[20,21] and Ile de France sheep[17] are similar to our findings and those that are recorded in camel[24] and Egyptian sheep.[15] Regarding the sphenoidal sinus, it was absolutely recognized in camel[24], Egyptian sheep[15], buffalo[22] and Ile de France sheep.[17] However palatine and sphenoid sinuses were not observed in goat.[16,20,21] buffalo,[22] camel,[24] and cattle.[26]

Studies on different ruminants showed no lack of a fissure in nasal bone in any of the samples. Naso-lacrimal fissure is mentioned in one of the goat specimens in Atlas of topographical anatomy of the domestic animals adjacent to the nasal, lacrimal and maxillary bones.[32] Due to the absence and naming of this fissure in any of the studies performed on ruminants, we named this fissure according to its location, as nasal fissure.

The frontal sinus in the Alborz wild sheep was limited to the frontal bone, without extending into the parietal, temporal or occipital bones similar to Saanen goat[16] and Ile de France sheep[17]. This observation was in contrast to the findings of Egyptian sheep[15] and Alsafy[22] and Saigal[33] in buffalo in which frontal sinuses were enclosed by the frontal and parietal bones. Moreover, the frontal sinus in giraffe[34] was reported to begin in the frontal bone and extend caudally to the parietal and interparietal and to the temporal bones laterally.

In this regard, camel is an exception among the large ruminant species as its frontal sinus is restricted to the frontal bone.[24] It is worth noting that the anatomy of the frontal sinus can be notably varied from horned ruminants to hornless ones. In the hornless breeds, such as Ile de France sheep, the frontal sinus is simply organized into two compartments with few septa and diverticula, while in the horned breeds such as Albors wild sheep and most goats, this sinus encompasses a complex architecture with numerous septa and interconnected diverticula which caudally extended with various depth into the horn core. In horned animals, this issue should be considered for dehorning.[35]

Contrary to Sisson[21] in small ruminants and Shojaei[23] in goat, which mentioned the extension of the maxillary sinus from the level of the first cheek tooth to the 4th cheek tooth, respectively, in this study the maxillary sinus extended from the level of the third pre-molar tooth to caudal to the last molar one. In the CT scan and cross sections of the skull of this breed, the maxillary sinus, contrary to the results of Seddek[36], Awaad[15] and Tohidifar,[16] was not divided into lateral and medal compartment and only had the dorsal compartment of maxillary sinus in the caudo-lateral part of sinus. On the other hand, Seddek,[36] Awaad,[15] and Tohidifar[16] revealed that the maxillary sinus was incompletely divided by the Infra-orbital canal into medial and lateral chambers.

The gross anatomy and CT in the current study together with Sisson[21] in small ruminants, Shojaei[23] and Masoudifard[17] in Ile de France sheep, point to the presence of the palatine sinus in the small ruminant, which, unlike the palatine sinus in horses, is not associated with the sphenoid sinus. This was inconsistent with Seddek,[36] Awaad[15] and Tohidifar's[16] results.

In this study, as in Masoudifard,[17] Tohidifar,[16] and Kareem and Sawad's[31] studies, no association was found between the lecrimal sinus and the frontal and maxillary sinuses. However, Kareem and Sawad[31] in goat considered this sinus as a part of the frontal sinus. In addition to that, Awaad[15] recorded a connection between the lacrimal and maxillary sinus by maxillo-lacrimal opening, while May[20] noticed this sinus opened into the middle nasal meatus. The conchal sinuses in our study showed the dorsal conchal, middle conchal and ventral conchal sinuses, which came in line with the results of Kareem and Sawad[31] as well as Tohidifar[16] in goat. On the other hand, May[20] and Sisson[21] in sheep, Moustafa and Kamel,[37] Saigal[33] and Alsafy[22] in buffalo, Alsafy[24] in camel and Mosoudifard[17] was not seen the ventral conchal sinus. The ventral conchal sinus was absent in Egyptian buffalo because of the presence of spiral lamellae within the caudal end of ventral nasal concha.[22]

Infra-orbital canal observed in this species, like other studies, starts from medial canthus of the eye and end in the infra- orbital foramen. The exact location of the infra-orbital foramen in this breed is in the range of first premolar teeth Which is similar to Sambar deer, but in Barking deer it is at level of third premolar tooth.[27] Also the infra–orbital foramen in Egyptian Buffalo is 1-2 cm above the alveolar border.[22]

The results of comparing the morphometric features of the skulls of Ile de France and Alborz wild sheep indicate that the length and width of the skulls of these two breeds are not much different from each other. However, the average height of the skull in Ile de France was 9.8 ± 0.93 cm and in Alborz wild sheep was 13.30 ± 0.63 cm, and this difference indicates that the height of the skull in this breed is larger than in Alborz wild sheep.

The average size of the first incisive tooth in Alborz wild sheep and Ile de France sheep[17] were 0.67 ± 0.33 and 0.55 ± 0.01 cm, respectively. Also, the average length of the first premolar and molar tooth in Ile de France sheep was 0.78 ± 0.22 and 1.62 ± 0.12 cm, respectively. The above indicates that all the teeth of Alborz wild sheep are larger than Ile de France sheep.

Ratio of nasal cavity volume to total skull volume in Alborz wild sheep, Saanen goat[16] and Ile de France sheep[17] was 0.1, 0.4 and 0.1, which indicates the equality of this ratio in Alborz wild sheep and Ile de France sheep. Also, a comparison of the ratio of eyeball volume to total head in these breeds indicates that this ratio is the lowest in Ile de France sheep[17] and the largest in Saanen goat,[16] respectively.

The largest paranasal sinus in Alborz wild sheep, like Saanen goat[16] and Ile de France sheep[17], was the frontal sinus. The smallest sinuses in Saanen goat were like Alborz wild sheep, lacrimal and in Ile de France sheep was palatine sinus.

We conclude that CT and radiographic anatomy are important to investigate the characteristic features of the paranasal sinuses as well as their relations and communications with the other cavities in the head region of the Alborz wild sheep. Also, these features were very important pre-requisites for diagnosis of the pathological conditions and clinical interference in head region.

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Conflict of Interest

The authors declare that they have no conflict of interest.

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