Iranian Veterinary Surgery Association

Iranian Journal of Veterinary Surgery

Journal homepage: www.ivsajournals.com

Original Article

Normal Computed Tomography and Radiographic Study of the Nasal Cavity and Paranasal Sinuses in Shal Sheep (*Ovis arries*)

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ARTICLE INFO

Article History:

Received 20 April 2023
Revised 29 June 2023
Accepted 10 July 2023
Online 10 July 2023

Keywords:

Computed tomography
Volumetric study
Morphometric study
Sheep
Skull

ABSTRACT

Understanding anatomical structures from the past to the present has been one of the guidelines for advancing medical and veterinary science worldwide. The lack of comprehensive information on the anatomy of the paranasal sinuses and the Shal sheep nasal cavity (*Ovis aries*) encouraged us to write this article. Computed tomography (CT) scan is a method that shows different parts of the body without superimposition of adjacent structures. Radiographic imaging also gives very high-resolution images of bones to examine bone structures. Paranasal sinuses of Shal sheep were composed of frontal, maxillary, lacrimal, and palatine sinuses, and the nasal sinuses were composed of dorsal, and middle nasal sinuses, which were identified and labeled in keeping with cheek teeth as landmarks. The width of the frontal bone and length of the nasal cavity at the level of the 6th cheek tooth were 7 ± 0.3 and 13 ± 0.8 cm, respectively. The volumes of both the right and left sinuses were measured automatically, and the accurate location of sinuses, canals, nasal folds, conchae, and meatuses, and connections between different parts of the nasal cavity and paranasal sinuses were described. The volume of the frontal, maxillary, and palatine sinuses were 279.3 ± 16.4, 80.6 ± 2.6, and 13.5 ± 0.2 cm^3, respectively. Frontal, maxillary, and lacrimal sinuses were observed like other ruminants. But the palatine sinus in this breed was not present in the Egyptian sheep, Saanen, and Markhz goats. Also, unlike Sanan and Markhz goats and like Egyptian sheep, ventral nasal sinus was not observed in this breed.

Introduction

The sheep and goat family, Bovidae, belongs to the even-toed ungulates order, Artiodactyla, so their body characteristics, especially the bones of the skull, can be similar to other ruminants. Shal sheep (*Ovis Arries*) is a domestic breed of Shal District in Buin Zahra Country, Qazvin Province, Iran, and is the best fleshy heavy-

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https://doi.org/10.30500/ivsa.2023.394056.1344

weighed breed in the country.[1] This specific species is well adapted to dry climates and is bred primarily for meat production than dairy, which is very important in this respect. It also has special features that make it highly economically viable and can improve the livestock economics of the country.[2]

The cranium in all mammals consists of two parts of the calvarium, the part that contains the brain, and the viscerocranium, the facial portion of the skull. More long head length, wider and longer ears, thicker muzzle, and relatively bigger eyes are considered in terms of specific appearance traits of the sheep compared to other mammals' breeds. The forehead is straight and short, and both sexes have no horns. From the profile view, the nose of this animal seems convex.[3]

Non-invasive diagnostic imaging techniques can provide accurate information about the body's organs. Computed tomography (CT) scan is one of the non-invasive techniques that uses an X-ray beam to give a sectional view of the body without superimposition of adjacent organs. In this way, valuable information is provided from different body parts with minimal invasion. In a head CT scan, useful information is obtained by giving 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 give us the reconstructed images of the area at different levels.[4] CT scan is an applied method for detecting spatial and transient lesions and is suitable for choosing surgical approaches. Therefor to properly interpret the lesions, knowing the normal anatomy is essential.[5,6,7] Surveys on the sinuses and the upper respiratory tract can also help us better understand respiratory disorders. In an investigation of the sheep's 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 humans.[8] Also, in a similar study, sheep were studied as a model of a large animal to examine the implantable hearing impairment in the middle and inner ear.[9] The advantage of CT scan as a biomechanical indicator is to demonstrate changes of goat's skull.[10]

Hollow bony cavities (sinuses) in sheep are of particular importance in cases of dental abscess due to their proximity to dental structures such as dental roots. Therefore, CT scan of these cavities is necessary in patients with dental abscess due to pus transfer inside them and sinusitis.

The aim of this study is to obtain comprehensive information about the nasal cavity and paranasal sinuses by CT scan and provide practical atlas for diagnostic imaging of the skull of Shal sheep (*Ovis arries*). In this study, we also try to compare the paranasal sinuses of this breed with other studies performed on Egyptian native sheep,[11] Saanen goat,[12] and Ile de France sheep.[13]

Materials and Methods

Sheep and Preparation of Materials

Six male clinically health sheep with an average age of three to four years old and weight of 55-65 kg were used in this study. Clinically health of the sheep was confirmed by clinical examination and the absence of bone deformities. The sheep were relatively similar in feed, storage temperature, and humidity. Diet, amount of taken vitamins (especially vitamin D) and minerals (especially calcium and phosphorus), and daily amount of sunlight were considered during the selection procedure. General anesthesia was performed for head CT scanning. 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.[14]

CT Examination

Each sheep was placed in sternal recumbency on the table, and it was advanced into the gantry manually. Laser markers were adjusted so that the perpendicular marker was located in front of nostrils and the horizontal marker was located at the center of the animal's body. All CT scans were obtained by two detector scanners (Siemens somatom spirit). The scanning parameters were as follows: rotation time, 1 s; slice thickness, 1mm; reconstruction interval, 0.5–1 mm; pitch, 1; X-ray tube potential, 100-110 kV; X-ray tube current, 130 mAs. The scanned images were started at the tip of the nose and covered the entire head to 2nd cervical vertebrae.[13] Images were reconstructed with Syngo MMWP VE40A software in 2D sagittal and frontal planes. Both window width (WW) and window level (WL) were adjusted due to interesting parts. The bone window was wont to examine the photographs. The obtained CT scan images in three transverse, longitudinal and sagittal views were named using pulmonary vascularization VP, bone and skin, and airway patterns.

Radiographic Examination

After preparing CT scan images of the skulls of Shal sheep, all samples were transferred to the radiation room for radiography and images of each sample were taken in two lateral (L) and dorsoventral (DV) views. The radiographic exposure factors were: 50 milliamperes, 0.1 seconds, 70-75 kilovolts of peak (KVP) for lateral, and 75-80 KVP for DV radiographs.

Analyzes

The skull morphometry of this sheep was evaluated by the RadiAnt application. The measurement results are shown in Tables 1 to 3 and Figure 1. The factors used in this study were taken from "Anatomy of the head in the Ile de France sheep: a computed tomographic and cross-sectional approach".[13] Volumetric calculations were performed on the paranasal sinuses, and nasal cavity of this breed was 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 manner, where the surface was calculated manually, it is obtained automatically by the software. Also, so as to extend the accuracy of the measurements, the average volume of every structure within the three views of transverse, longitudinal, and sagittal has been announced. The volumetric measurements were recorded for each sheep separately and they were analyzed by SPSS 2022 software and a paired sample t-test ($p \geq 0.05$).

Results

Nasal Cavity

The nasal cavity extends from the nostrils to the level of the eyes at the ethmoidal labyrinth (Figure 6/14 and /22). The nasal septum divides the nasal cavity into two equal parts, left and right. There were canals, folds, and concha in this cavity that we will mention in the following. There are some structures, such as infraorbital foramen and cheek tooth in this section, which have been selected as a criterion for measuring and locating other parts due to their external appearance (Table 4).

Canals. Infraorbital canal opens onto the maxilla at the infraorbital foramen and continues up to 6nd cheek teeth (Figure 2/14). Infraorbital foramen was more rostrally in comparison with the rostral margin of the maxillary sinus. This canal extends up and back in the maxillary sinus (Figures 2/9 and 6/32). The nasolacrimal duct was between the rostral part of 5nd cheek teeth and the middle part of 6nd cheek teeth and

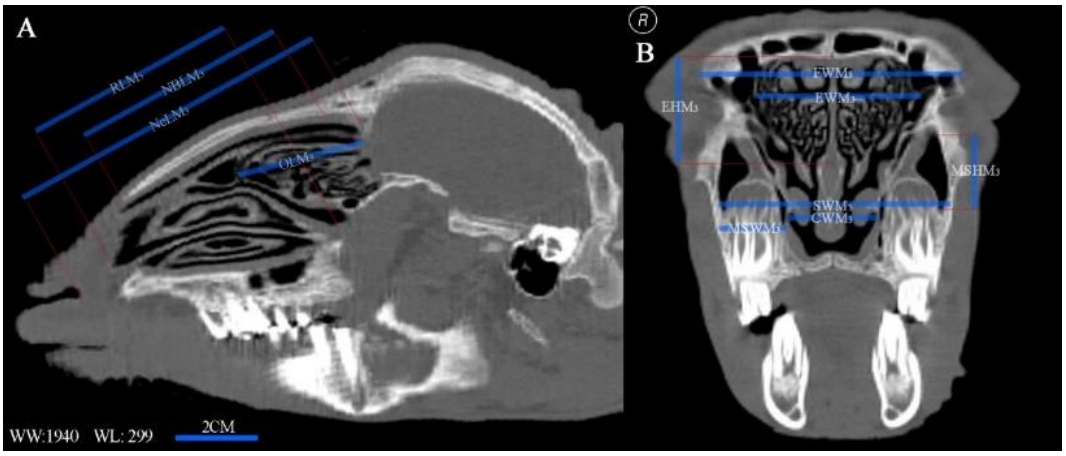

Figure 1. 2D CT scan images (longitudinal and transverse view – bone window) of morphometric parameters in the Shal sheep. **(A)** Longitudinal section at level of middle part of lower 3rd upper molar tooth (PM_3)**; (B)** transverse section at level of middle part of right 3rd upper molar tooth (PM_3). (RLM_3) Respiratory region length at level of longitudinal section of middle part of right 3rd upper molar tooth (M_3); ($NBLM_3$) Nasal bone length at level of longitudinal section of middle part of right 3rd upper molar tooth (M_3); ($NcLM_3$) Nasal cavity length at level of longitudinal section of middle part of right 3rd upper molar tooth (M_3); (OLM_3) Olfactory rejoin length at level of longitudinal section of middle part of right 3rd upper molar tooth (M_3); (FWM_3) Frontal bone width at level of transvers section of middle part of right 3rd upper molar tooth (M_3); (EWM_3) Ethmoidal labyrinth width at level of transvers section of middle part of right 3rd upper molar tooth (M_3); (EHM_3) Ethmoidal labyrinth height at level of transvers section of middle part of right 3rd upper molar tooth (M_3); ($MSHM_3$) Maxillary sinus height at level of transvers section of middle part of right 3rd upper molar tooth (M_3); (SWM_3) Skull width at level of transvers section of middle part of right 3rd upper molar tooth (M_3); (CWM_3) Choanae width at level of transvers section of middle part of right 3rd upper molar tooth (M_3); ($MSWM_3$) Maxillary sinus width at level of transvers section of middle part of right 3rd upper molar tooth (M_3).

Table1. Morphometric study parameters and descriptions in the skull of Shal sheep. (RLM_3) Respiratory rejoin length at level of longitudinal section of middle part of right 3rd upper molar tooth (M_3); ($NBLM_3$) Nasal bone length at level of longitudinal section of middle part of right 3rd upper molar tooth (M_3); ($NcLM_3$) Nasal cavity length at level of longitudinal section of middle part of right 3rd upper molar tooth (M_3); (OLM_3) Olfactory rejoin length at level of longitudinal section of middle part of right 3rd upper molar tooth (M_3); (CWM_3) Choanae width at level of transvers section of middle part of right 3rd upper molar tooth (M_3); (EWM_3) Ethmoidal labyrinth width at level of transvers section of middle part of right 3rd upper molar tooth (M3); (IOcL) Infraorbital canal length; (FWM_3) Frontal bone width at level of transvers section of middle part of right 3rd upper molar tooth (M_3); (SWM3) Skull width at level of transvers section of middle part of right 3rd upper molar tooth (M_3); (EHM_3) Ethmoidal labyrinth height at level of transvers section of middle part of right 3rd upper molar tooth (M_3); ($MSHM_3$) Maxillary sinus height at level of transvers section of middle part of right 3rd upper molar tooth (M_3); ($MSWM_3$) Maxillary sinus width at level of transvers section of middle part of right 3rd upper molar tooth (M_3); (SOcL) Supraorbital canal length.

Parameters	Description
RLM_3	The distance between the end of respiratory region district and the beginning of conchas at level of longitudinal section of middle part of 3rd upper molar tooth (M_3).
$NBLM_3$	The distance between start of nasal bone and start of frontal bone which was associated with the onset of the frontal sinus at level of longitudinal section of middle part of 3rd upper molar tooth (M_3).
$NcLM_3$	The length of nasal cavity from fold areas to ethmoidal labyrinth at level of longitudinal section of middle part of 3rd upper molar tooth (M_3).
OLM_3	The length of olfactory region which it was located between the end area of respiratory region and ethmoidal labyrinth.
CWM_3	The width of nasal cavity which lead from the nasal cavities to the nasopharynx.
EWM_3	The largest width of ethmoidal labyrinth conchas at level of longitudinal section of middle part of 3rd upper molar tooth (M_3).
IOcL	The length of start of infraorbital canal which was in medioventral part of eye ball to infraorbital foramen which was located in the anterior part of the 2nd upper premolar tooth.
FWM_3	The maximum distance between the two sides of the frontal bone conchas at level of longitudinal section of middle part of 3rd upper molar tooth (M_3).
SWM_3	The maximum distance between the two sides of the maxillary bone conchas at level of longitudinal section of middle part of 3rd upper molar tooth (M_3).
EHM_3	The height of ethmoidal labyrinth Which is located between the floor of the frontal sinus and the lowest part of these labyrinths.
$MSHM_3$	The maximum height of maxillary sinus at level of transvers section of middle part of 3rd upper molar tooth (M_3).
$MSWM_3$	The maximum width of maxillary sinus at level of transvers section of middle part of 3rd upper molar tooth (M_3).
SOcL	The length of start of supraorbital canal which was opened in the last third of the eye ball to middle part of frontal sinus.

Table2. Morphometric results of nasal cavity in the skull of Shal sheep. (RLM_3) Respiratory rejoin length at level of longitudinal section of middle part of right 3rd upper molar tooth (M_3); ($NBLM_3$) Nasal bone length at level of longitudinal section of middle part of right 3rd upper molar tooth (M_3); ($NcLM_3$) Nasal cavity length at level of longitudinal section of middle part of right 3rd upper molar tooth (M_3); (OLM_3) Olfactory rejoin length at level of longitudinal section of middle part of right 3rd upper molar tooth (M_3); (CWM_3) Choanae width at level of transvers section of middle part of right 3rd upper molar tooth (M_3); (EWM_3) Ethmoidal labyrinth width at level of transvers section of middle part of right 3rd upper molar tooth (M3); (IOcL) Infraorbital canal length. (M) Male. The unit of measurement is centimeters (cm).

No.	RLM_3	$NBLM_3$	$NcLM_3$	OLM_3	CWM_3	EWM_3	IOcL
M_1	8.2	6.0	12.6	3.1	1.9	4.1	4.6
M_2	7.1	5.8	13.6	3.5	2.2	4.0	4.5
M_3	8.2	5.0	14.0	3.8	2.0	3.8	5.0
M_4	8.0	5.3	12.0	3.8	2.3	4.4	5.1
M_5	7.5	5.4	13.6	3.4	1.8	4.4	4.8
M_6	7.7	5.0	12.1	4.0	1.9	3.9	5.1
Mean ± SD	7.7 ± 0.4	5.4 ± 0.4	13 ± 0.8	3.6 ± 0.3	2.0 ± 0.2	4.1 ± 0.2	4.9 ± 0.2

Table3. Morphometric results of sinuses in the skull of Shal sheep. (FWM_3) Frontal bone width at level of transvers section of middle part of right 3rd upper molar tooth (M_3); (SWM_3) Skull width at level of transvers section of middle part of right 3rd upper molar tooth (M_3); (EHM_3) Ethmoidal labyrinth height at level of transvers section of middle part of right 3rd upper molar tooth (M_3); ($MSHM_3$) Maxillary sinus height at level of transvers section of middle part of right 3rd upper molar tooth (M_3); ($MSWM_3$) Maxillary sinus width at level of transvers section of middle part of right 3rd upper molar tooth (M_3); (SOcL) Supraorbital canal length. (M) Male. The unit of measurements is centimeters (cm).

No.	FWM_3	SWM_3	EHM_3	$MSHM_3$	$MSWM_3$	SOcL
M_1	7.2	6.5	3.2	2.2	1.8	1.9
M_2	6.7	6.3	2.4	2.3	1.5	1.5
M_3	6.6	5.5	3.3	2.1	1.2	1.8
M_4	7.4	5.8	2.5	2.2	1.4	2
M_5	7.2	6.2	2.4	2.3	1.6	1.6
M_6	6.9	6.2	2.4	2.5	1.5	1.5
Mean ± SD	7.0 ± 0.3	6.0 ± 0.3	2.7 ± 0.4	2.3 ± 0.1	1.5 ± 0.2	1.7 ± 0.2

Table4. Location of paranasal sinuses and canals inside the nasal cavity due to their proximity to the cheek teeth. (**+**) Means the presence of sinus or canal in the tooth level was specified and (**-**) means the absence of sinus or canal in the tooth level was specified.

Structure	1st upper premolar tooth (PM_1)	2nd upper premolar tooth (PM_2)	3rd upper premolar tooth (PM_3)	1st upper molar tooth (M_1)	2nd upper molar tooth (M_2)	3rd upper molar tooth (M_3)	Post alveolar region
Frontal sinus	-	-	-	-	-	+	+ Up to one third of posterior portion of orbit
Maxillary sinus	-	+ From posterior	+	+	+	+	+
Palatine sinus	-	+ From middle	+	+	+ Up to the middle	-	-
Lacrimal sinus	-	-	-	-	-	+	-
Dorsal conchal sinus	+	+	+	+	+	+ Up to the middle	-
middle conchal sinus	-	-	+ From posterior	+	+	+ Up to the middle	-
Nasolacrimal duct	-	-	-	-	+	+ From middle	-
Infraorbital canal	-	+ From anterior	+	+	+	+	-
Supraorbital canal	-	-	-	-	-	-	+
Lacrimal bulla	-	-	-	-	-	-	+

has rostroventral protraction and maxillary sinus was more ventrally and laterally than this duct. Infraorbital canal started more caudally, ventrally, and medially in comparison with the nasolacrimal duct (Figures 2/23 and 6/33).

Folds. The basal fold began before the anterior edge of the incisive bone and continued up to the anterior edge of the basal (Figure 2/1). The alar fold started at the anterior border of the incisive bone and continued up to the middle portion of the palatine fissure. The straight fold started from the beginning of the palatine fissure and was as far as the nasal bones continued (Figure 7/2).

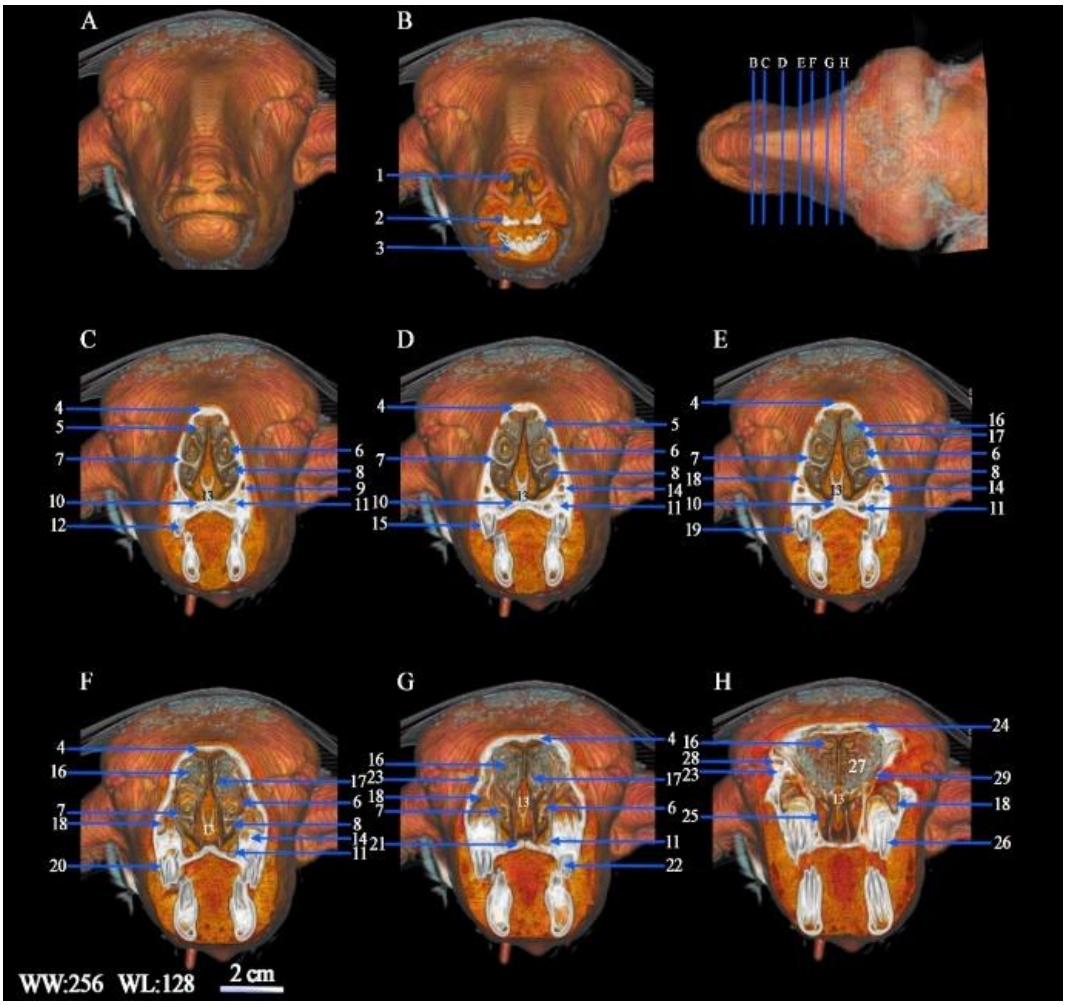

Figure 2. 3D CT scan images of nasal cavity (transverse view – pulmonary vascularization vp pattern) in the Shal sheep. **(A)** Full view of the head from the front**; (B)** cross section at level incisive tooth; (**C)** cross section at level of 1nd cheek teeth; **(D)** cross section at level of 2nd cheek teeth; **(E)** cross section at level of 3nd cheek teeth; **(F)** cross section at level of 4nd cheek teeth; **(G)** cross section at level of 5nd cheek teeth; **(H)** cross section at level of 6nd cheek teeth. (1) Basal fold; (2) hard plate; (3) incisive tooth; (4) nasal bone; (5) dorsal nasal concha; (6) dorsal spiral of ventral nasal concha; (7) ventral nasal concha; (8) ventral spiral of ventral nasal concha; (9) infraorbital foramen; (10) palatine process of maxilla; (11) palatine sinus; (12) 1nd cheek teeth; (13) nasal septum; (14) infraorbital canal; (15) 2nd cheek teeth; (16) dorsal conchal sinus; (17) middle conchal sinus; (18) maxillary sinus; (19) 3nd cheek teeth; (20) 4nd cheek teeth; (21) horizontal plate of palatine bone; (22) 5nd cheek teeth; (23) nasolacrimal duct; (24) frontal bone; (25) choanae; (26) 6nd cheek teeth; (27) ethmoidal labyrinth; (28) lacrimal sinus; (29) lacrimal sinus opening to middle nasal concha.

Concha. Dorsal nasal concha saw as far as dorsal conchal sinus continued (Figures 2/5, 4/27, 5/12, and 6/11). Middle nasal concha was followed with ethmoid concha at the level of 2nd cheek teeth up to the postalveolar region (Figures 4/25 and 6/12). Ventral nasal concha ended up to the anterior part of the 6nd cheek teeth. Also, in most parts, the ventral nasal concha was in the form of the dorsal and ventral spiral of the ventral nasal concha (Figures 2/6, 7, 8, 4/28, and 6/13).

Paranasal Sinuses

The paranasal sinuses in shal sheep comprised the frontal, maxillary, lacrimal, palatine, dorsal, and middle conchal sinus, which were recognized and considered in keeping with cheek teeth as markers. Sphenoid and ethmoidal sinuses were not observed in this breed, which has been further studied in the discussion section. The stable position of premolar and molar teeth in the hard palate makes recognizing structures easier, as previously studied by Shojaei *et al.*[15] The accurate location of sinuses, canals, nasal folds, conchaes, and meatuses and connections between different parts of nasal cavity and paranasal sinuses were described from rostral to caudal in Table 1.

Frontal Sinus. The frontal sinus generally covers the roof of the skull. It was started from the 6nd cheek teeth and continued up to caudal one-third of the

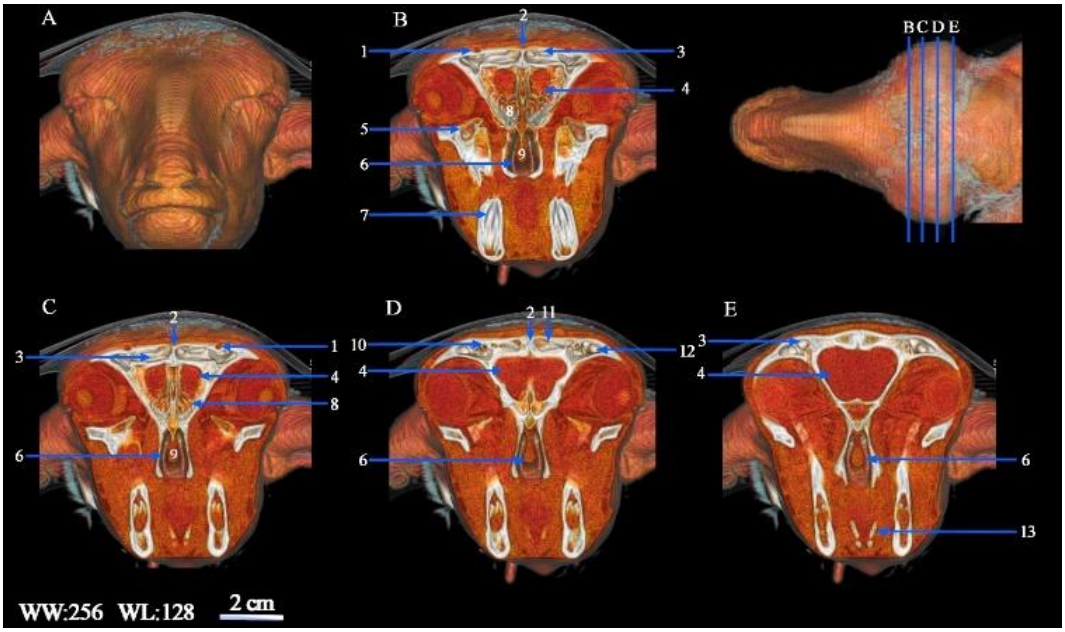

Figure 3. 3D CT scan images of sinuses (transverse view – pulmonary vascularization vp pattern) in the Shal sheep. **(A)** Full view of the head from the front**; (B)** cross section at level of 6nd cheek teeth; (**C)** cross section at level of the middle part of eye ball; **(D)** cross section at level of 1cm caudal to C; **(E)** cross section at level of the last third of eye ball. (1) Supraorbital foramen; (2) inter frontal septum; (3) frontal sinus; (4) brain; (5) lacrimal bulla; (6) Choanae; (7) root of 3nd cheek teeth; (8) ethmoidal labyrinth; (9) vomer; (10) supraorbital canal; (11) middle group of compartments of frontal sinus; (12) post- orbital diverticulum of the caudal group of compartments of frontal sinus; (13) Hyoid bone.

postalveolar region (Figures 3/3, 4/12, 5/3, and 6/15). Frontal sinus connected with lacrimal sinus at its medial part, dorsal to endoturbinates, and the middle portion of 6nd cheek teeth. The supraorbital canal has passed through the middle of this sinus and ends in the last third of the eyeball (Figure 2/2 and /10).

A bony plate called interfrontal septum divides the frontal sinus into equal parts left and right from beginning to end. The end part of both sides of the frontal sinus is also divided into two parts, postorbital diverticulum of the caudal group of compartments of frontal sinus and the middle group of compartments of the frontal sinus (Figure 3/12 and /13).

Maxillary Sinus. Maxillary sinus started at the posterior part of 2nd cheek teeth and continued up to the caudal and ventral of the postalveolar region (from posterior to anterior one-third of the orbit), which is named lacrimal bulla that had communication with maxillary sinus in its rostral parts (Figure 3/5). The maxillary sinus continues parallel to the nasal cavity, and a thin wall separates it from the ventral nasal concha (Figures 2/18, 4/29, and 5/8). In the middle of this sinus, there is a sac at the lower edge of the lacrimal sinus in front of the eyeball, but there is no way through it. The whole infraorbital canal also passes through this sinus and 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. The maxillary sinus communicates with the nasal cavity in three parts: at the level of the first molar tooth, second molar tooth, and third molar tooth. The last connection between the maxillary and nasal cavity is down to lacrimal sinus and nasal cavity communication. Palatine and maxillary sinuses connected at the level of 3nd cheek teeth through the dorsal aspect of infraorbital canal.

Palatine Sinus. The anterior part of the palatine sinus starts at level of the middle part of 2nd cheek teeth and the caudal part continues to the middle part of the 5nd cheek teeth. The palatine sinus was located between the level of the middle part of 2nd cheek teeth and the middle part of the 5nd cheek teeth. This sinus was at the ventromedial aspect of the maxillary sinus, and it has a straight connection with it at all parts (Figure 2/11). Also, this sinus, like the maxillary sinus, has a close relationship to the root of teeth, and it makes them in danger of dental sinusitis.

Lacrimal Sinus. The lacrimal sinus was located in the lateral part of the maxillary sinus and started at the level of the 6nd cheek teeth and continued parallel to the root of this tooth (Figures 2/28, 3/30, and 5/10). This sinus was located in the medial position of the nasal cavity and its end part was in the anterior

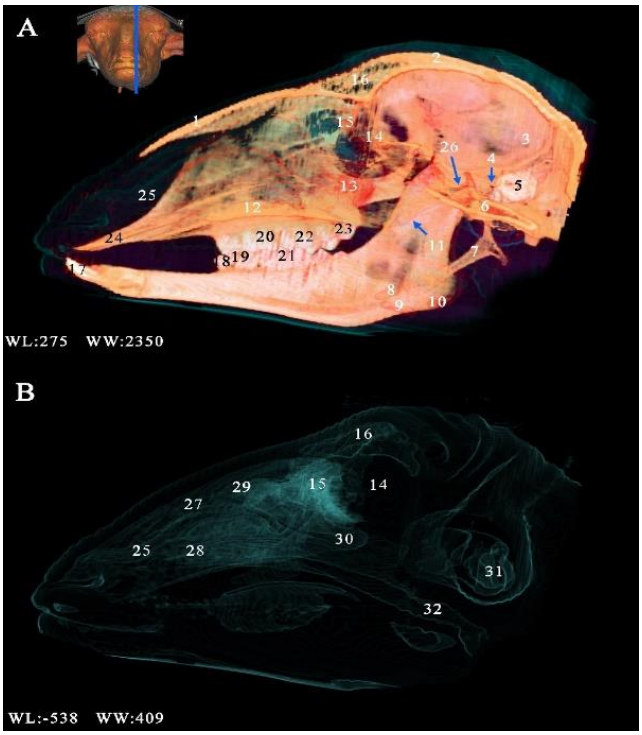

Figure 4. 3D CT scan images of skull (Longitudinal view) in the Shal sheep. **(A)** bone and skin; **(B)** Air way view. (1) Nasal bone; (2) frontal bone; (3) parietal bone; (4) internal acoustic meatus; (5) petrous part of temporal bone; (6) basisphenoid; (7) stylohyoid; (8) epyhyoid; (9) ceratohyoid; (10) angle of mandible; (11) pterygoid bone; (12) palatine process of maxilla; (13) zygomatic bone; (14) eye ball; (15) ethmoidal labyrinth; (16) frontal sinus; (17) incisive tooth; (18) first pre molar tooth (1nd cheek tooth); (19) second pre molar tooth (2nd cheek tooth); (20) third pre molar tooth (3nd cheek tooth); (21) first pre molar tooth (4nd cheek tooth); (22) second pre molar tooth (5nd cheek tooth); (23) third pre molar tooth (6nd cheek tooth); (24) incisive bone; (25) middle nasal concha; (26) TemporoMandibular Joint (TMJ); (27) dorsal nasal concha; (28) ventral nasal concha; (29) maxillary sinus; (30) lacrimal sinus; (31) tympanic bulla; (32) nasopharynx.

position of the maxillary sinus. This sinus is also associated with the nasal cavity in the position of the middle 6nd teeth. Also, in the end, it has a connection with the rostral parts of the frontal sinus (Figure 2/29).

Dorsal Conchal Sinus. This sinus is located in the middle of the dorsal nasal concha, which was started at the level of 1st cheek teeth and continues to the middle part of the 6nd cheek teeth. We found a short communication with frontal sinus at the end of this sinus. Unlike the middle conchal sinus, this sinus was directly connected to the rostral wall of the brain (Figure 2/16).

Middle Conchal Sinus. The middle conchal sinus started at the level of 3nd cheek teeth and continued down to the dorsal conchal sinus to the ethmoidal labyrinth, and unlike that, it has no communication with any other sinuses (Figure 2/17).

Morphometric Study

The criteria used to measure the morphometric structures of the nasal cavity, and paranasal sinuses in this breed are given in Table 1. In line with the measurements made within the nasal cavity, the average length of the nasal cavity, respiratory and olfactory region in the six samples were calculated as 13 ± 0.8, 7.7 ± 0.4 and 3.6 ± 0.3 cm, respectively. Also, the average length of infraorbital canal was 4.9 ± 0.2, and also the width of choanae was 2.0 ± 0.2 cm. The average width of the frontal bone was 7 ± 0.3 cm, and the length of the nasal bone was 5.4 ± 0.4 cm. Also, the width and height of the maxillary sinus at the level of the third molar tooth were measured, on average, 1.5 ± 0.2 and 2.3 ± 0.1 cm, respectively.

Volumetric Study

According to the information in Table 3, the largest sinus in this breed of small ruminants was the frontal sinus with a volume of 279.3 ± 16.3 cm^3 and the smallest sinus was the palatine sinus with a volume of 13.5 ± 0.2 cm^3. The volume of maxillary and lacrimal sinuses was also 80.6 ± 2.6 and 14.2 ± 1.2 cm^3, respectively. The dorsal and middle conchal sinuses, which are located in the nasal cavity, were 31.3 ± 1.8 and 13.9 ± 0.7 cm^3 on average, respectively. The statistical studies conducted on the volume data of the skull of the Shal sheep indicated that there is a significant difference ($p \geq 0.05$) between the volume of all the sinuses with each other.

Discussion

The use of radiographic images to study the skull structures of animals has been used by researchers in this field from the past to the present.[16] Also, in recent years, due to the development of diagnostic imaging, the approach of researchers in this field to use cross-sectional CT scan images has increased.[13,12] Among the studies performed to identify the anatomical areas of the skull of animals, we can mention Buffalo,[17] Goat,[18] Rayini Goat,[19] Camel,[20] Donkey (*Equus asinus*),[21] Cattle,[22] Egyptian native sheep,[8] Saanen Goat,[12] Barking deer and Sambar deer,[23] and Ile de France sheep.[13]

The complexity of how different parts of the skull relate to each other has been proven to everyone. On the other hand, due to the proximity of air, soft tissue and bony structures in the skull, these structures and their relationship with each other can be seen on CT scan images.[24]

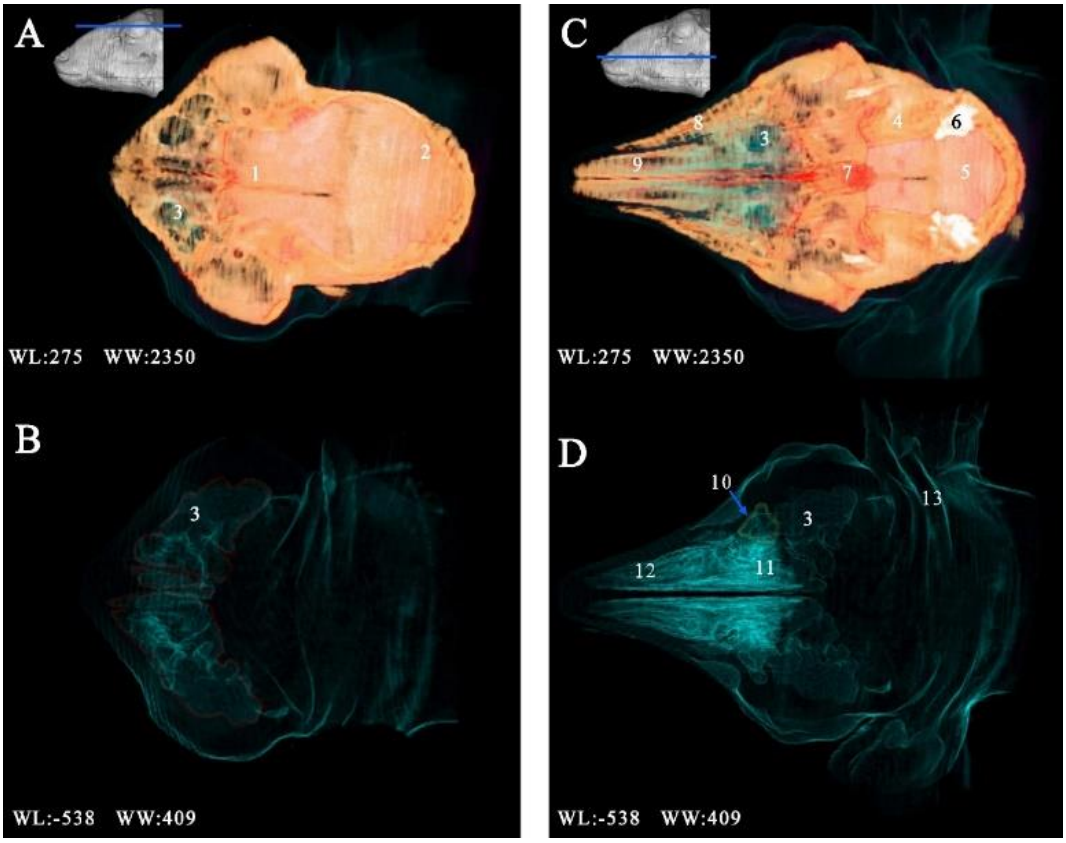

Figure 5. 3D CT scan images of skull (sagittal view) in the Shal sheep. **(A)** bone and skin view at level of slightly higher than eye ball; **(B)** Air way view at level of slightly higher than eye ball; **(C)** bone & skin view at level of 2.3 cm lower than eye ball; **(D)** Air way view at level of 2.3 cm lower than eye ball. (1) frontal bone; (2) parietal bone; (3) frontal sinus; (4) tympanic bulla; (5) basilar part of occipital bone; (6) occipital condyle; (7) vomer; (8) maxillary sinus; (9) incisive bone (10) lacrimal sinus; (11) ethmoidal labyrinth; (12) nasal concha; (13) acoustic meatus.

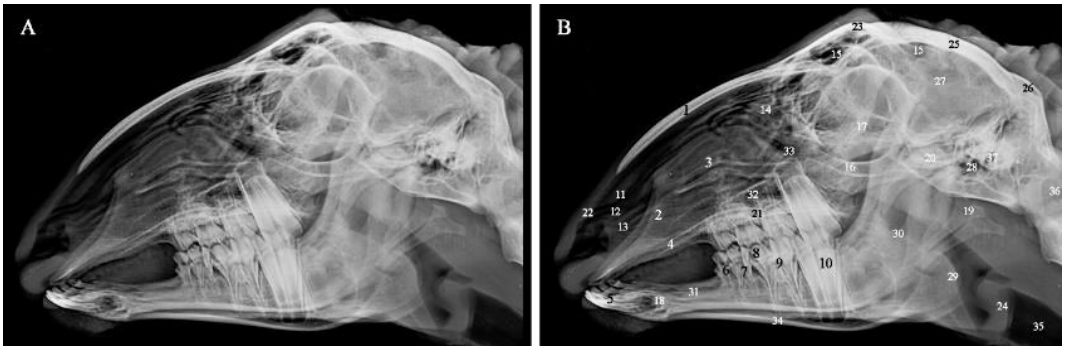

Figure 6. Radiograph images of skull (Lateral view) in the Shal sheep. **(A)** Image without number**; (B)** numeral image. (1) Nasal bone; (2) incisive bone; (3) maxilla; (4) palatine process of incisive bone; (5) incisive tooth; (6) 1nd cheek teeth; (7) 2nd cheek teeth; (8) 3nd cheek teeth; (9) 5nd cheek teeth; (10) 6nd cheek teeth; (11) dorsal nasal concha; (12) middle nasal concha; (13) ventral nasal concha; (14) ethmoidal labyrinth; (15) frontal sinus; (16) zygomatic arch; (17) orbit; (18) mental foramen; (19) stylohyoid bone; (20) TemporoMandibular Joint (TMJ); (21) palatine process of maxilla; (22) nostril; (23) frontal bone; (24) larynx; (25) parietal bone; (26) squamous part of occipital; (27) lateral wall of neurocranium; (28) tympanic bulla; (29) angle of mandible; (30) mandible; (31) interalveolar space or diastema;(32) infraorbital canal; (33) nasolacrimal duct; (34) ventral border of mandible; (35) trachea; (36) atlas; (37) external acoustic meatus.

The nasal sinuses in this breed included the dorsal conchal and middle conchal sinuses, which was in line with the results of Mosoudifard[13] in Ile de France sheep, Alsafy[20] in camel, Alsafy[17] in buffalo, Saigal and Khatra[8] in boffalo, and Moustafa and Kamel[25] in Egyptian buffalo, Sisson[18] and May[26] in sheep. But contrary to the results of Konig and Liebich in domestic animals, Kareem and Sawad[27] in goats also Tohidifar[12] research, ventral nasal sinus was not observed in this breed. The ventral conchal sinus was absent in Egyptian Buffalo and Ile de France sheep because of spiral lamellae within the caudal end of the ventral nasal concha.[13,17]

Figure 7. Radiograph images of skull (Dorsoventral view) in the Shal sheep. **(A)** Image without number**; (B)** numeral image. (1) Incisive tooth; (2) palatine fissure; (3) vomer; (4) 1nd cheek teeth; (5) 2nd cheek teeth; (6) 3nd cheek teeth; (7) 4nd cheek teeth; (8) 5nd cheek teeth; (9) 6nd cheek teeth; (10) zygomatic arch; (11) hyoid bone; (12) maxillary sinus; (13) maxilla; (14) mandible; (15) perpendicular part of palatine; (16) presphenoid; (17) tympanic bulla; (18) foramen magnum; (19) occipital condyle; (20) external acoustic meatus.

Table5. Volumetric results of sinuses in the skull of Shal sheep. The volume measured in each of maxillary, palatine, lacrimal, dorsal conchal and middle conchal sinus is on one side of the skull (M) Male. The unit of measurement is cubic centimeters (cm^3).

No	Fontal sinus	Maxillary sinus	Palatine sinus	Lacrimal sinus	Dorsal conchal sinus	Middle conchal sinus	Nasal cavity
M_1	300.2	81.6	12.3	15.0	32.2	13.5	1625.6
M^2	299.3	80.6	13.5	16.2	30.8	13.2	1536.0
M^3	280.2	79.3	13.3	13.8	31.8	14.3	1575.3
M^4	278.5	77.3	14.6	12.5	28.9	14.0	1500.2
M^5	260.0	85.6	15.6	13.8	29.6	15.3	1650.2
M^6	258.9	79.3	12.0	13.7	34.5	13.6	1526.5
Mean ± SD	279.316.4	80.6 ± 2.6	13.5 ± 1.2	14.2 ± 1.2	31.3 ± 1.8	13.9 ± 0.7	1568.9 ± 53.9

Like other studies, the infraorbital canal observed in this species starts from the medial canthus of the eye and ends in infraorbital foramen. The exact location of the infraorbital foramen in this breed is in the range of second premolar teeth, but in Barking deer and Sambar deer species, it is at the level of third and first premolar teeth respectively.[23] Also, the infraorbital foramen in Egyptian Buffalo is 1-2 cm above the alveolar border.[17]

In similarity of results with Alsafy[17] in buffalo, this study demonstrated a short curved supraorbital canal that passes via the caudal frontal sinus.

The present work showed that the Shal sheep head contained maxillary, frontal, and lacrimal sinuses similar to all examined ruminant species. Also, the palatine sinus, unlike in cattle,[22] Egyptian sheep,[11] camel,[20] and Saanen goat,[12] was seen in shal sheep. The presence of palatine sinus has been reported by May,[26] Sisson and Grossman[18] in sheep, Shojaei[19] in Rayini goat, Alsafy[17] in buffalo, Kareem and Sawad[27] in Iraqi goat, and also Masoudifard[13] in Ile de France sheep.

Regarding the sphenoidal sinus, it was identified in goat,[10] buffalo,[17] Egyptian sheep,[11] camel,[20] and Ile de France sheep.[13] Also, in line with our observation of the Shal sheep, the sphenoidal sinus was not observed in local Iraqi goats[27] and Saanen goats.[12]

The results of our observations indicated the

absence of frontal sinus in a bone other than the frontal bone, and this finding was contrary to Awaad[11] in Egyptian sheep and Alsafy[17] in buffalo in which the frontal and parietal bones enclosed frontal sinuses studies. In addition, the frontal sinus in giraffes[28] was stated to start within the frontal bone and spread caudally to the parietal and inter-parietal and to the temporal bones laterally.

Our observations showed that the anterior part of the maxillary sinus was at the level of the second premolar tooth and the end of this sinus was caudal of the last upper molar tooth. These observations confirm the results of Awaad[11] in Egyptian sheep and Tohidifar[12] in Saanen goat. This extension was more extensive than those reported in Rayini goat by Shojaei.[19] Just as mentioned above, the maxillary sinus has three communication parts with the nasal cavity. The only communication between the maxillary sinus and nasal cavity in Egyptian native sheep[11] was naso-maxillary opening between the medial compartment of the maxillary sinus and the middle nasal concha. Also, this communication in Egyptian Buffalo[17] was with the middle nasal meatus in the caudal part. This communication was in common with the palatine sinuses through naso-maxillary opening. The communication between the maxillary sinus and nasal cavity was not mentioned in Saanen goat.[12]

The lateral compartment of the rostral frontal sinus was connected to the lacrimal sinus. This finding corroborated the observations reported on sheep,[26] local Iraqi goats,[27] and Saanen goats.[12] In addition, our study has not recorded the communication between the lacrimal and maxillary sinus by maxillo-lacrimal opening, which Awaad[11] in Egyptian sheep mentioned the absence of this opening.

To consider the palatine sinus as a separate sinus from the maxillary sinus is a case that has been reported differently in different studies. In the shal sheep, like May,[26] Sisson and Grossman,[18] Dyce and Wensing,[3] Alsafy,[17] Alsafy,[20] Tohidifar,[12] and Masoudifard,[13] this sinus is separate from the maxillary sinus but is in direct contact with it.

The biggest skull sinus in the Shal sheep was the frontal sinus, which corresponded with Saanen goat[12] and Ile de France sheep results.[13] The volume of the frontal sinus in the Shal sheep was 279.3 ± 16.4 cm^3, but it was 281.8 ± 16.9 cm^3 in saanen goat.[12] Also, the smallest sinus was the palatine sinus, with 13.5 ± 1.2 cm^3 volume, while the middle conchal sinus, with 13.4 ± 2.6 cm^3 volume, was the smallest in Saanen goat.[12] The maxillary and lacrimal sinus and nasal cavity volumes were 80.6 ± 2.6, 14.2 ± 1.2, and 1568.9 ± 53.9 cm^3, respectively. However, these volumes were 169.8 ± 13.1, 50.2 ± 0.6, and 829.4 ± 62.6 cm^3 in Saanen goats.[12]

The ratio of frontal sinus to maxillary in the Shal sheep was 3.4, while this ratio was 1.65 in Saanen goats and 1.6 in Ile de France sheep. Also, the maxillary sinus was six times larger than the palatine sinus, and the dorsal nasal sinus was 2.3 times larger than the middle nasal sinus. Although these were 13 and 1.8 in Ile de France sheep. The percentage of nasal cavity occupation by dorsal and middle nasal sinus was 2% and less than 1%, respectively. This ratio was 2.6% and 1.4% in Ile de France sheep.[13]

CT scans and radiographs are among the best tools to examine the skull of a shal sheep with a scarf and the connections between the sinuses and different parts of the skull. Understanding these anatomical features is also an essential prerequisite for diagnosing pathological conditions and diseases related to the skull of this breed.

Conflict of Interest

The authors declare no conflict of interest.

Acknowledgment

Thanks to the employee of the anatomy department of the Faculty of Veterinary Medicine, University of Tehran, who did his best to carry out this project.

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