The Scientific Journal of University of Benghazi

http://journals.uob.edu.ly/sjuob

Morphological study of the cranial bones of the Libyan fox (*Vulpes rueppellii*) in the north-eastern region of Libya

Abdelgader K Youssef*, Ahmed W Ahmed, Neema A Darnawi

Zoology department- Faculty of sciences- Benghazi University.

Received date: 26 / 03 / 2021; Accepted date: 05 / 12 / 2021

الملخص

في هذا البحث وُضّحَ شكل أنواع عظام جمجمة الثعلب الليبي Vulpes rueppellii التي تخص المكونات الرئيسة الثلاث:

1) القرنيوم الأدمي والمحتوي على: الفكي الأمامي، الفكي، الأنفي، الجبهي والجداري.

2) القرنيوم العصبي الذي تكونه العظام الوسطى مثل: هيكل المحافظ الحسية، صندوق المخ والإطار الحجاجي.

3) القرنيوم الحشوي المتمثل في العظام الفكية السفلى والفكية العلوية المبطنة للناحية البطنية للقرنيوم العصبي.

الدراسة كذلك تطرقت لشكل القوس الخدي إلى العظام الخلفية للجمجمة والمكونة للثقب الكبير مثل اللقم القذالية والعظام المجاورة السمعية. الدراسة تضمنت التمفصل الحاصل بين عظام الجمجمة وما تحتويه من ثقوب لمخارج الأعصاب ومداخلها والأوعية الدموية. لم يغفل البحث وصف أنواع الأسنان المحمولة على الفكين وتحديد القانون السني لهذا النوع من الثعالب الآكلة للحوم.

الكلمات المفتاحية:

جمجمة، فك، ثعلب *Vulpes rueppellii*.

Abstract

The cranial bones of a wild Libyan fox (Vulpes rueppellii) has been studied. The specimens were collected from different regions of Cyrenaica province. The skull was small and delicate, and the tympanic bulla was well developed. The dental formula was: I 3/3, C 1/1, P 4/4, M 2/3, total 42. Mental foramina and the angular process of the mandible were present.

Keywords: Vulpes rueppelli, fox, skull, mandible.

1. INTRODUCTION

The skeleton of mammalian skull is always under the surface [1], and it is related to the axial skeleton. The fox is from the family of canidae which is the most prominent carnivores that occur throughout most of the world. Canidae occupy every continent except Antarctica [2].

Despite the wide range of the foxes, little is known about the species, which are listed as Data Deficient by International Union for Conservation of Nature [3]. The other genera of foxes as mention by sillero-zubiri et al. [2] are: 1. *Vulpes bengalensis* Indian fox, 2. *Vulpes cana* Blanford's fox, 3. *Vulpes chama* Cape fox, 4. *Vulpes corsac* Corsac fox, 5. *Vulpes ferrilata* Tibetan fox, 6. *Vulpes macrotis* Kit fox, 7. *Vulpes pallida* Pale fox, 8. *Vulpes velox* Swift fox, 9. *Vulpes vulpes* Red fox, 10. *Vulpes zerda* Fennec fox.

Some subspecies have been described externally (size and color) by Ellerman and Morison [4], the observation indicate that there was high variability between these specimens [5, 6, 7].

The objectives of this study was to investigate the cranial bones of *V. Rueppelli* fox, thereby making a contribution to filling the gap of knowledge in this part of the fox skeleton.

*__Correspondence__:

Abdelgader K Youssef
Abdulgaderkhalifa4@gmail.com

Canidae are known from Africa since the Miocene [8]. Remains may belong to either V. *rueppelli* or *V. zerda* were occur in late Pliocene deposits of Ahl al Oughlam in Morocco [9]. Vulpes rueppelli diverged from other Vulpes later than V. zerda, suggesting that it entered desert regions more recently [10]. The closest relative to *V. rueppelli* is *V. bengalensis*, *V. vulpes*, or *Alopex lagopus* [11, 10].

Harrison [12] remarked that the skull of *Vulpes ruppelli* is small and delicate and its tympanic bullae are well developed. The distance between the anterior orbital margin and gnathion is slightly shorter than the distance between the same point and the posterior part of the zygoma. Nasal bones are short, upwardly deflected posteriorly, and slightly constricted medially. Braincase does not have a strong ridge: temporal ridges pass directly backward from the posterior root of the postorbital process and remain widely divergent until just in front of lambda.

Rosevear [6] remarked that the skull of *Vulpes ruppelli* is like a smaller sidestriped jackal (*Canis adustus*), but without well-developed occipital crests. The braincase is rounded, the postorbital processes are blunt and narrow, the zygomatic arches are strong, and the bullae are relatively large but not so expanded as in fennec fox. The cranium of *Vulpes ruppellii* aged individual from Dahl Al-Hanan region (Saudi Arabia) was with greatest length of skull 102.0, condyle basal length 97.4, zygomatic breadth 58.4 and interorbital constriction 19.7 mm, it fits into the sample recorded by Harrison [12].

Harrison and Bates [13] observed that the braincase in the skull of *Vulpes cana* is small and narrow anteriorly and the palate strikingly narrow.

Red foxes display sexual dimorphism in body weight and proportions in many areas [14, 15, 16, 17] including differences between male and female red fox skulls from several different regions [18, 19, 15, 20, 21, 22, 23]. Additional research found that parasites could modify skull dimensions in other species [24]. The total skull length of corsac foxes was smaller than the red foxes, whose skulls range from 140-150 mm [25, 26]. In addition, corsac foxes have a less-developed sagittal crest, a more gradually tapering rostrum, and smaller, flatter auditory bullae than do red foxes [27, 28, 26, 29].

In a comparative study of the skulls in red fox and corsac foxes (*Vulpes corsac*), Munkhzul et al [29] were found that the external sagittal crest of the red fox arises at the junction of the temporal lines, near the interparietal bone. Their interfrontal and interparietal sutures were typically serrated. Also, they found significantly different skull measurements for most morphological features between corsac foxes and red foxes. They observed that corsac foxes demonstrated smaller, shorter and wider skulls, and with more robust canine teeth. They found that the corsac fox had a less-developed and lower external sagittal and nuchal crests than did the red fox. In the red fox, the low ridges extended back from the postorbital processes, with the temporal lines of the postorbital processes converging at an acute angle at the boundary of the frontal and parietal bones and forming a V-shape on top of the skull alternatively, in corsac foxes the temporal lines diverged from the postorbital processes, ran nearly parallel on top of the skull with an under-developed interparietal suture, and converged near the posterior suture of the parietal bones. The squamous part of the occipital bone in the corsac fox was smaller than in the red fox. The occipital condyles, paracondylar process and tympanic bullae in the red fox were all better developed than in the corsac fox. The upper side of the foramen magnum was wider and more arched in the red fox, while that of the corsac foxes was more oval.

As mentioned by Ansorge [22], the Length parameters of the red fox skulls almost reach full size by 6 months of age, but width dimensions continue increasing until the second year of life.

Batsaikhan et al. [30] suggested that skulls greater than 130 mm in length come from red foxes, while skulls less than 130 mm in length come from corsac foxes. Heptner et al. [31] stated that corsac fox skull lengths range between 95 and 112 mm and suggested if the total length of skull is >115 mm then it comes from a red fox. In addition, Scokolov and Orlov [27] reported that the total length of red fox skulls varied between 130 and 160 mm.

In their description of the Crab-eating fox (Cerdocyonthous), Barison et al. [32] found that it has a caudally elongated skull with the larger temporal zygomatic process. The incomplete orbits are located in the middle distance between the occipital and nasal bones laterally.

In comparison between the red fox and raccoon dog, Jurgelenas et al. [33] observed that the external sagittal crest at the margin of the interparietal bone in both of them was well developed. They found a double condylar canal in red fox, the open of the canal occurred in the ventral condylar fossa and the paracondylar processes extended ventrolaterally. The red fox has an oval-shape foramen magnum with a V-shaped ventral margin and doubles ethmoidal foramen. The frontal sinus area in red fox showed very thin osseous partitions and there is no overlap with the zygomatic processes. In the median part of the frontal sinuses has only one apparent partition. In a comparative study of the skulls in red fox and arctic foxes (*Vulpes lagopus*), Frackowiak et al. [34] were found that the most important morphological differences occurred within craniometric measurements, especially in the nasal, occipital, and temporal bones, and the parietal, maxilla, and mandible areas. Karan et al. [35] observed that well-articulated zygomatic processes of the frontal bones are typical of dogs, badges, and martens, whereas in cats they extend to the frontal processes of the zygomatic bones. In addition, Jurgelenas et al. [33] reported that the frontal sinuses in raccoon dog nearly fully overlap with zygomatic processes. In contrast, the zygomatic processes in red fox are not interrupted by the frontal sinuses, which was confirmed by macroscopic and computed tomography examination, these processes were well developed in raccoon dog and red fox, but their direction was different which were ventrolateral in raccoon dog and lateral in red fox.

The overlap of frontal sinuses with zygomatic bones was also reported in Beagle dogs by Fike et al. [36], as well as in Akita dogs and Japanese wolves (*Canis hodophilax*) by Endo et al. [37]. Jurgelenas et al. [33] remarked that the mandible of red fox has a pointed angular process, the ventral margin of its ramus has a flat indentation, the entire surface of ramus was occupied with the masseteric fossa, and the posterior end of mandible formed an angulo-articular hook-shaped process.

Munkhzul et al. [29] observed that the red fox and corsac fox have two mental foramina of the mandible. Red foxes' masseteric fossa was deeper and wider than in corsac foxes. In addition, the mandibular notch and angular process were slightly better developed in the red fox. In the red foxes, the lower edge of the ramus curved gently back to the end of the angle, but in the corsac foxes, the lower edge of ramus showed a distinct step, or break, just in front of the angle.

The dental formula have been identified as I 3/3, C 1/1, P 4/4, M 2/3, total 42 in rüppell's fox [12, 6]; I3/3, C1/1, P3/3, M2/2, total 36 in otter [38]; I3/2-3, C1/1, P2-4/2-4, M1/1-2 in the Mustelidae family [39, 40].

2. MATERIALS AND METHODS

The selected specimen is the Libyan fox (*Vulpes rueppellii*) (Fig. 1) which is classified as following by Wozencraft[41]:

Kingdom: Animalia

Phylum: Chordata

Subphylum: Vertebrata

Group: Gnathostomata

Superclass: Tetrapoda

Infraclass: Amniota (Warm-blooded animal)

Class: Mammalia (Eutheria)

Order: Carnivora

Family: Canidae

Genus: *Vulpes*

Species: *rueppellii*

Subspecies: *Cyrenaica*

Figure 1. Rüppell's fox (*Vulpes rueppellii*)**.**

Due to the little information and the similarity between Libyan fox and other species, this kind of foxes was selected to study the bones of its skull. It is found across North Africa, within these regions: Algeria, central Niger, Libya and northern Chad [42].

Ten specimens were collected from different regions of Cyrenaica province (Fig. 2): one from Taknis, two from Tokra, one from Sidi Khalifa, two from Nawaguea, two from Jardena, one from Soltan and one from Al Mabni. Each fox was given code, which is an abbreviation of the region in which it was found. The foxes found dead on the roads, which were hit by cars, and dead on farms and coastal beaches.

The specimens were found dead and collected between 2017 and 2019. To get rid of the muscles and skin, two methods were mentioned by Stephen and Nawrocki [43] and used to obtain the bones:

1. The first method was by burying the specimen. The specimen was buried immediately after obtaining it and to accelerate the process of decomposition was used Calcium oxide (CaO). The period of burial differed from one specimen to another according to working conditions. The minimum duration was two months (the specimen of the Taknis) and the longest period was about a year and half (the specimen of the Tokra), this method was applied to most specimens.

Figure 2. Cyrenaica province, northeast Libya.

2. After extracting the specimens from the burying, the only structures that found are the bones, skin and fur residues, the skin was removed very carefully using hands and forceps to obtain bone only. The bones were then cleaned of dirt, soil and skin residue using a toothbrush and hot water, sometimes the skin is strongly attached to the bones and to be removed without damaging the bones, it was soaked in the ammonia solution (NH3) for several minutes and then cleaned by the forceps and toothbrush.

3. The second method was by dissecting the corpse immediately after obtaining it by removing the internal organs, skinning the skin and removing all the muscles using the anatomy tools and the ammonia solution.

4. After the completion of the cleaning, the bones are gray because of the length of the burial period or because of the effect of cleaning materials on them, and for bleaching them are sprayed with hydrogen peroxide (H_2O_2) and left to dry slowly in a dark, or by soaking in potassium hydroxide (KOH) for a few minutes and then let it dry slowly under the sun.

5. To study the components of the skull, one of the skulls had to be disassembled by distilling some droplets from the ammonia solution on the sutures between the bones of the skull and leaving it for several minutes, then separated the bones from each other using the hands carefully because of the sensitivity of these bones.

6. The bones were kept in special tubes and boxes containing naphthalene (C10H8), which was used as a preservative and each bone was given its symbol. Several bone pictures were taken in several different cameras throughout the study period and these pictures were modified by the paint program. The morphological description was applied on the skull and mandible.

3. RESULTS

I. Morphological descriptive of skull bones:

The skull is the first part of the axial skeleton, it is small, delicate and composed of several separate bones that joined together by sutures. These bones are as follow:

Premaxilla bone (Pr): Irregular paired premaxilla bones, with incisors in the anterior end. There are three pointed processes extend from the caudal region of each bone. The longest of the processes is the upper one. In the two short lower processes, the internal is longer than the external one (Figs. 3,5,7,9 and 12).

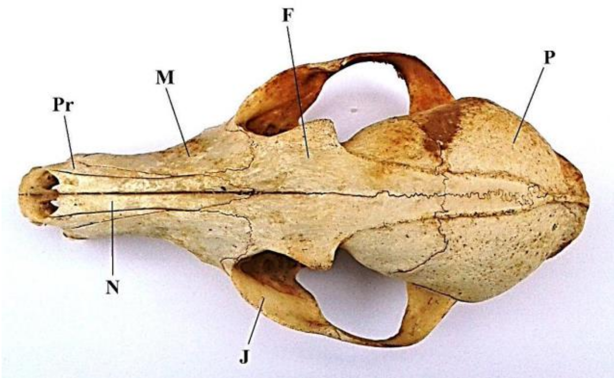

Figure 3. Dorsal view of *Vulpes rueppellii* skull

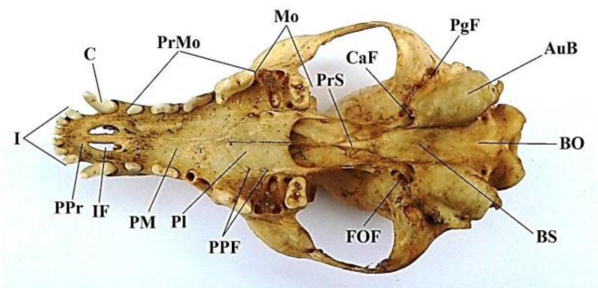

Figure 4. Ventral view of *Vulpes rueppellii* skull

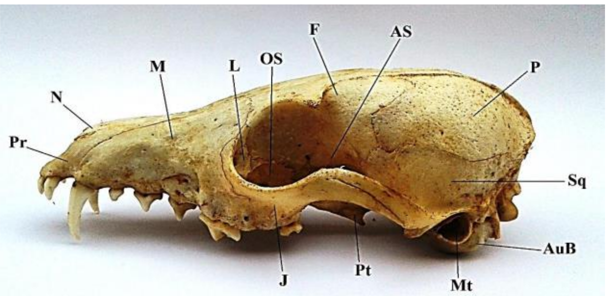

Figure 5. Lateral view of *Vulpes rueppellii* skull

Maxilla bone (M): Paired triangular maxillary bones, with lower long and upper short edges, the lower one bears all upper teeth except the incisors. Posteriorly each bone has a big concavity to the orbit. Laterally there is the infraorbital foramen (Figs. 3,5,7,8,9 and 13).

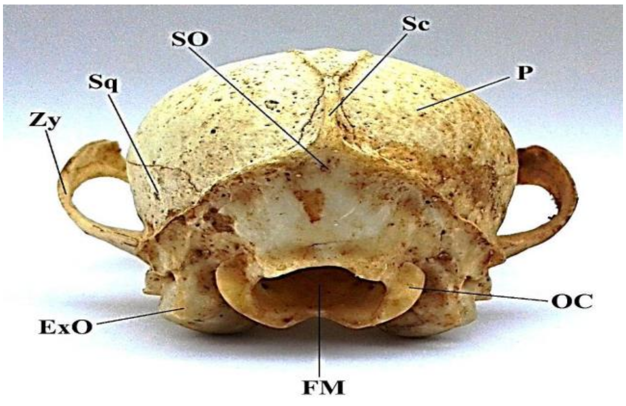

Figure 6. Caudal view of *Vulpes rueppellii* skull

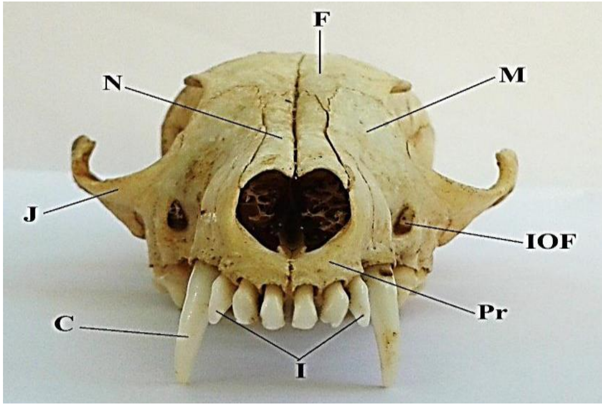

Figure 7. Anterior view of *Vulpes rueppellii* skull

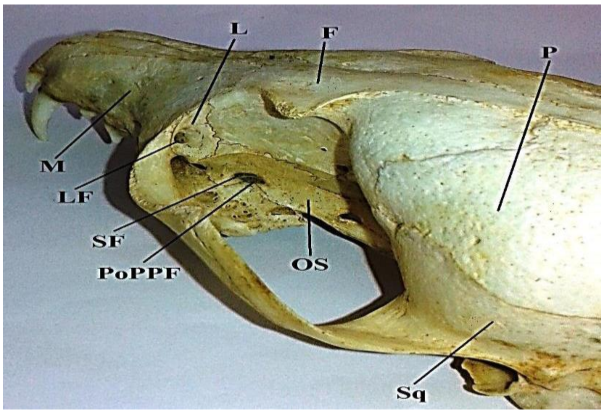

Figure 8. Anterior Orbital Foramina of *Vulpes rueppellii* skull

3. Nasal bone (N): Paired long rod-shaped nasal bones, dorsally flat, ventrally each bone forming a groove that is separated by a bony barrier. Rostrally each side ends with V-shaped arms, the internal arm is shorter than the external one. It caudolaterally ends forming a spoon shape (Figs. 3,7,9 and 14).

4. Frontal bone (F): Paired frontal bone is relatively large, dorsally, there are extend wing-shaped. Ventrally, it's separated by a horizontal ridge (Figs. 3,5,7,8,9,10 and 15).

5. Lachrymal bone (L): Small paired dorsally pointed bones, with tear foramen at the narrow area (Figs. 5 and 8).

6. Jugal bone (J): A strong paired zygomatic arch consists of anterior Y-shaped zygomatic process of the maxilla and posterior zygomatic process of squamosal. A paired strong maxillary processes unite posteriorly with the zygomatic process of the squamosal to complete the zygomatic arch (Figs. 5,7,9 and 16).

7. Parietal bone (P): Paired plate-like bones, convex externally, concave internally. Ventrocaudally, there is a thin bone like bat connect parietal bones together (Figs. 3,5,6,8,9,10 and 17).

8. Squamosal bone (Sq): Paired squamosal bones have a horn-shaped process (Figs. ,5,6,8,9 and 16).

9. Occipital bones (O): Formed of supra-, basi- and ex-occipital bones which lie at the sides of the foramen magnum and each bears an oval prominence condyle closely to the tympanic bulla (Figs. 4,6 and 11).

10. Palatine bones (Pl): Arise as horizontal shelves of bone from premaxilla, maxilla and palatine bone (Fig. 4).

11. Vomer (V): Paired thin long bone with a pair of delicate lateral wings. Ventrally there is a barrier along the median plane progressively disappear in the caudal region (Fig. 18).

12. Pterygoid bone (Pt): Small irregular thin paired bones, each with a caudal process of the alisphenoid (Fig. 5).

13. Sphenoid bones (S): A plate of bones include the presphenoid and the basisphenoid, both of them connected laterally with irregular plates, the basisphenoid are posterior to the alisphenoid and the orbitosphenoid are anterior to the presphenoid (Figs. 4,5,8 and 9).

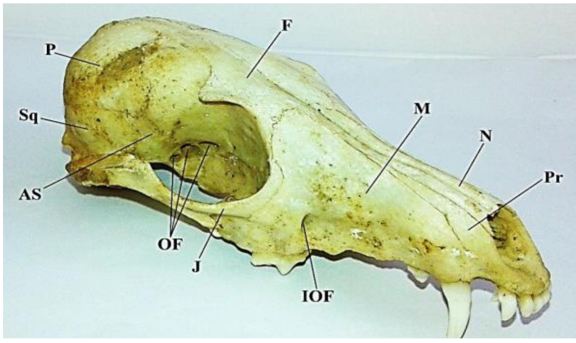

Figure 9. Posterior Orbital Foramina of *Vulpes rueppellii* skull

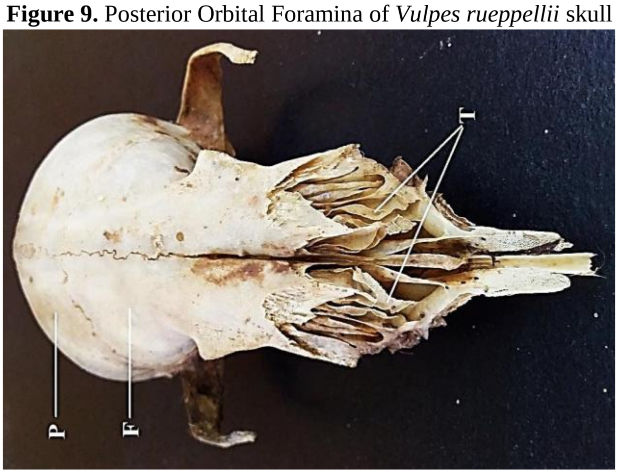

Figure 10. Anterior view of skull showing the scrolls barriers of turbinals

14. Auditory bullae (AuB): The auditory bullae are oval capsules with external auditory meatus (Figs. 4,5,11 and 16).

15. Periotic (Pe): It is a bone of irregular shape with internal depression (temporal fossa). The periotic and tympanic are loosely connected with surrounding bones. It is lying lateral to the supra-occipital (Figs. 4, 5 and 6).

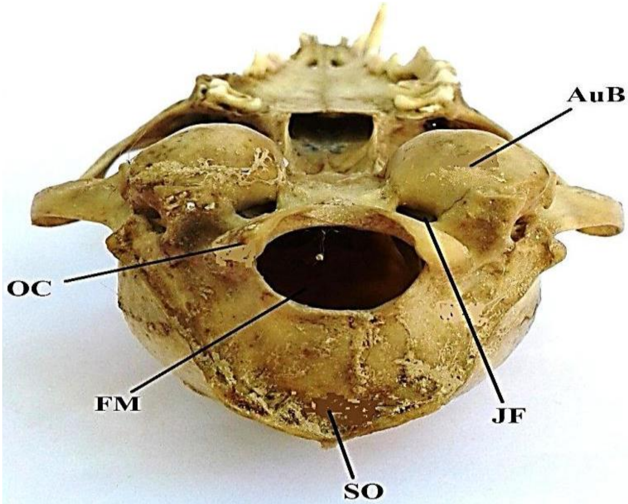

Figure 11. Caudal view of skull, lying on dorsal side.

Figure 12. Internal lateral view of right premaxilla.

Figure 13. External lateral view of left maxilla

16. Ethmoid complex (E): It is part of olfactory capsules (Fig. 5) that consists of a cribriform plate perforated by olfactory nerve foramina, perpendicular mesethmoid plate of nasal septum and several turbinal elements (conches) see articulation.

17. Mandible (Ma): It consists of two lateral halves (rami), each ramus represents a single bone known as the dentary. The dentary extends posteriorly as the angular process and dorsally

as the coronoid process with a triangular-shaped coronoid fossa laterally. The condyle is in between the mentioned two processes. Each half of the lower jaw bears the heterodont dentition (Fig. 19). The dental formula was: I3/3 + C1/1 + P4/4 + M2/3 × 2.

. The foramina of the skull:

The skull has many openings for the passage of nerves and blood vessels and sometimes other structures:

1. Incisive foramina (IF): Large oval-shaped in the anterior end of the dorsal side of the mouth cavity, it's connected to the roof of the mouth with nasal cavities (Fig. 4).

2. Infraorbital foramen (IOF): Large foramen in the maxilla bone forms an infraorbital canal lying under lachrymal at the anterior base of the zygomatic arch, it's a passage to the fifth (trigeminal) nerve and blood vessels (Fig. 7).

3. Lachrymal (Tear) foramen (LF): Small foramen at the narrow area of the lachrymal bone passing through the maxilla into the nasal cavities to form the tear canal for the draining of the tear (Fig. 8).

4. Posterior palatine foramen (PPF): Small foramen lying at the suture between the palatine process of the maxilla and the palatine bone, forms the anterior opening of the palatine canal, the posterior opening of this canal is at caudal end of the expanded mass of the maxilla which located in the orbit (Figs. 9 and 13), it's the passage of the branch of the fifth (trigeminal) nerve into the palate (Fig. 4).

Figure 14. Ventral view of nasal bones.

Figure 15. Anterior view of the internal frontal bones.

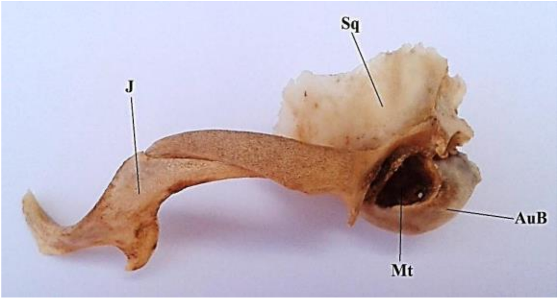

Figure 16. Lateral view of left zygomatic arch.

5. Sphenopalatine foramen (SF): Small foramen lying dorsally to the posterior opening of the palatine canal located in the anterior orbital wall, it's the passage of the branch of the fifth (trigeminal) nerve into the nasal cavity (Fig. 8).

Figure 17. Ventral view of parietal bones.

Figure 18. Ventral view of vomer carrying turbinals

6. Optic foramina (OF):

There are four optic foramina in the posterior orbital wall (Figs. 4 and 9), as follow:

A. First optic foramen (FiOF): It is the anterior foramen of the four infraorbital foramina that occur in alisphenoid and it's a passage of the second (optic) nerve.

B. Second optic foramen (SOF): It is the largest of the four foramina, lying posterior to the first optic foramen and it is the passage of the third (coulomotor), fourth (trochlear), and sixth (abducens) nerves of the eyeball, and the greater part of the fifth (trigeminal) nerve.

C. Third optic foramen (TOF): It is lying posterior to the second optic foramen, forms a small canal for transmits a branch of the fifth (trigeminal) nerve. D. Fourth optic foramen (FOF): It is the last of the four foramina that lying posterior to the third optic foramen which transmits branch of the fifth (trigeminal) nerve.

7. Carotid foramen (CaF): It is irregular foramen lying at the anterior ventral end of the auditory bulla as well as posterior to the fourth optic foramen and it's a passage to the internal carotid artery (Fig. 4).

8. Jugular foramen (JF): Oval-shaped foramen lying between the auditory bulla and the basioccipital bone which is a passage of the ninth (glossopharyngeal), tenth (vagus), and eleventh (spinal accessory) nerves (Fig. 11).

9. Postglenoid foramen (PgF): Small foramen in the squamosal bone lying under the posterior base of the zygomatic arch as well as above the external auditory meatus (Fig. 4).

III. The foramina of the mandible:

1. Mandibular foramen (MaF): Small foramen at the posterior end of the dentary on the internal surface through which the nerve enters and pursues a course in the interior of the mandible to the mental foramen (Fig. 19.A).

2. Mental foramen (MeF): Two foramina lying at the anterior end of the dentary on the outer surface through which the nerve of the lower jaw (Fig. 19.B).

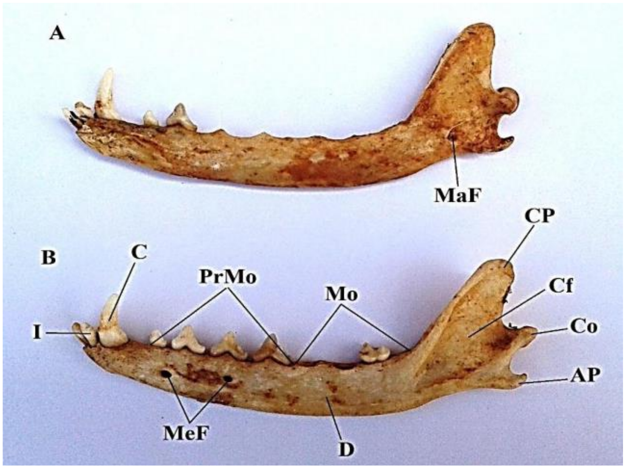

Figure 19. Lateral view of mandible: A. Internal right side. B. External left side.

Articulation between skull bones:

Usually in vertebrates, bones of the skull connected to each other by fibrous connective tissues to forming the different bones of the main crania as follow:

A. First optic foramen (FiOF): It is the anterior foramen of the four infraorbital foramina that occur in alisphenoid and it's a passage of the second (optic) nerve.

B. Second optic foramen (SOF): It is the largest of the four foramina, lying posterior to the first optic foramen and it is the passage of the third (coulomotor), fourth (trochlear), and sixth (abducens) nerves of the eyeball, and the greater part of the fifth (trigeminal) nerve.

C. Third optic foramen (TOF): It is lying posterior to the second optic foramen, forms a small canal for transmits a branch of the fifth (trigeminal) nerve. D. Fourth optic foramen (FOF): It is the last of the four foramina that lying posterior to the third optic foramen which transmits branch of the fifth (trigeminal) nerve.

7. Carotid foramen (CaF): It is irregular foramen lying at the anterior ventral end of the auditory bulla as well as posterior to the fourth optic foramen and it's a passage to the internal carotid artery (Fig. 4).

8. Jugular foramen (JF): Oval-shaped foramen lying between the auditory bulla and the basioccipital bone which is a passage of the ninth (glossopharyngeal), tenth (vagus), and eleventh (spinal accessory) nerves (figure 11).

9. Postglenoid foramen (PgF): Small foramen in the squamosal bone lying under the posterior base of the zygomatic arch as well as above the external auditory meatus (Fig. 4).

III. The foramina of the mandible:

1. Mandibular foramen (MaF): Small foramen at the posterior end of the dentary on the internal surface through which the nerve enters and pursues a course in the interior of the mandible to the mental foramen (figure 19.A).

2. Mental foramen (MeF): Two foramina lying at the anterior end of the dentary on the outer surface through which the nerve of the lower jaw (Fig. 19.B).

Articulation between skull bones:

Usually in vertebrates, bones of the skull connected to each other by fibrous connective tissues to forming the different bones of the main crania as follow:

1. Premaxilla (Pr): Large bones forming the anterior part of the snout. They bear the upper incisor teeth and give off three processes nasal, palatine and maxillary. It's forming the floor of the large nasal foramen. Laterodorsally, they overlapped between the nasal and the maxilla bones. Ventrally, fused with maxillary palatine plates to form the palatine processes of premaxillae, the processes of premaxilla form the rostral edges of the pair incisive foramina (palatine foramina). The anterior edges of the maxillary palatine processes forming the caudal edges of the incisive foramina, the caudal border of these processes fused with the palatine plates (Figs. 3,4,5,7 and 9).

2. Maxilla (M): Paired large triangular bones with posterior concave edges, this large irregularlyshaped bones form the greater part of the upper jaw, and bear the canine, premolar and molar teeth. They make up the large area of the face, their dorsal borders fused with premaxilla, nasal and frontal (see the descriptive of latter bones). The caudal border forms the anterior base of the zygomatic arch, it's dorsoposterioly convex edges fused with the anterior concave edges of the frontal. The anterior lateral portions of frontal, lachrymal and the anterior base of jugal meet at the middle posterior edge of the maxilla. Ventrally, the maxillary palatine plates fused with each other along the median plane under the vomer to form the middle region of the palate. The palatine plates of palatine and for maxillae help to bound the nasal cavities externally, each bears internally a pair of thin scroll-like bones (the maxillo-turbinals) (Figs. 3,4,5,7,8 and 9).

 ISSN:Online 2790-1637, Print 2790-1629; National Library of Libya, Legal number : 154/2018

3. Nasal bone (N): It is a pair dorsal median planes on the face, each bone fused with the other along the internal side. Rostrally, processes of the two nasal bones beside each other giving a Wshape appearance. Caudally, together form pointed pike-shape overlapping with the anterior V-shape of the frontal. The anterior half-length of each lateral external nasal border fused with premaxilla and the other posterior half-length overlapped with the maxilla and with the pointed processes of frontal V-shape (Figs. 3,7,9 and 14).

4. Frontals (F): Its position is in the dorsal middle of the skull lying front the parietal and they are forming the anterior-most roof of the braincase. The left and right frontal bones fused together along their dorsomedial line and fused with the nasal, maxilla and lachrymal bones anteriorly (see latter bones). Ventrocaudally, between the frontal and the alisphenoid there is a broad squamosal bone. Each lateral frontal bones form part of the upper portion of the inner wall of the orbit. Above each orbit is a curved crescentic supraorbital process (Figs. 3,5,7,8,9 and 10).

5. Lachrymal (L): As mention in the maxilla, lachrymals are irregularly small bones, each situated in the anterior wall of the orbit, behind the posterior edges of the maxilla, it is fused caudally in between the lateral frontal, orbitosphenoid and the anterior base of the zygomatic process. The bone perforated by a small aperture (lachrymal foramen) (Figs. 5 and 8).

6. Parietal bones (P): They are plate-like bones, convex externally and concave internally forming the dorsal caudal region of the skull, as well as forming the posterior roof of the braincase. They articulate rostrally with frontals, laterally with squamosals and caudally with the supraoccipital bone. Internally, the posterior edges of parietal supported with thin wing-shape bone connect the two sides and support them, the space between the two wing bone receive a pointed process of the supra-occipital that extend inside the cavity of the parietal. The upper internal supra-occipital process appears externally as a sagittal crest between the parietals and supra-occipital bone (Figs. 3,5,6,8,9 and 10).

7. Squamosal bones (Sq): Posteriorly the squamosal gives off a flat post-tympanic process that applied to the outer surface of periotic. Each side of the periotic bone forms a dilated tympanic bulla. Internally, the periotic bone enclosing the membranous labyrinth of the internal ear. The squamosal bone produces a strong zygomatic process which curves outwards then forwards to unite with the jugal in the formation of the zygomatic arch. Strong process originates from the outer face of each maxilla and turning outwards then backward to unite with the zygomatic process of the squamosal and thus to complete the zygomatic arch (Figs. 5,6,8 and 9).

8. Occipital bone (O): It's formed the posterior region of the braincase, the supra-occipital overlapped dorsally with the parietal bones by using triangularly pointed process. The basioccipital is formed the posterior floor of the braincase, it is fused anteriorly with the basisphenoid and laterally with the auditory bulla. In the posterior wall of the skull is a large rounded foramen magnum this open is flanked with a pair of smooth rounded condyles (occipital condyle) for articulation with the first vertebra. Each condyle produces below a process of paraoccipital, closely applied to the tympanic bulla. The sutures between these bones are strongly fused and impossible to distinguish the components of the occipital (Figs. 4,6 and 11).

9. Palatine bone (Pl): It's forming the roof of the oral cavity, as well as the floor of the nasopharynx cavity, the palatine bone fused caudally with the pterygoid and the presphenoid bones and laterally with the orbitosphenoid (Fig. 4).

10. Sphenoid bones (S): The orbitosphenoid fused: dorsally with the ventral lateral edge of the frontal bones, anteriorly with lachrymal bone and posteriorly with the alisphenoid bone, that is fused caudally with the squamosal bone. The orbitosphenoid with the alisphenoid together are forming the lower wall of the orbit. The basisphenoid overlapping: caudally with the basioccipital, laterally with both the alisphenoid and the pterygoid bones add to that it is fused anteriorly with the presphenoid which fused anteriorly with the vomer (Figs. 4,5,8 and 9).

11. The vomer (V): It has a head of an arrow-shape, with pair lateral wings. It's located upper the palatine bones forming the floor of the nasal cavity, as well as the roof of the nasopharynx cavity. It's ventral vertical walls separating the nasopharynx cavity into two sides and anteriorly it is overlapping by its forward pointed process with premaxilla process and caudally with presphenoid bone. Upper the vomer there are the turbinals (Fig. 10), which are very thin scrolls bones that increase the respiratory and olfactory surface and consist of maxillary-, naso- and ethmo-turbinals. The turbinals are covered completely by premaxilla, maxilla, nasal and dorsolateral sides of frontal (Fig. 18).

4. DISCUSSION

Libyan fox (*V. ruppellii*) are species of canidae living in the northeastern region of Libya. The main aim of the present study was to study the skull skeleton of these species and to find the most important differences that distinguish them from other species of canidae.

Here are some foxes in the world that characterized by researches on some bones of the skull, the arrangement of [12] this discussion includes different cranial regions.

All the structures of *Vulpes ruppelli* skull that has been characterized by Harrison and Rosevear [6] are similar to what found in this study that the skull is small and delicate, tympanic bullae are well developed, braincase does not have a strong ridge and the zygomatic arches are strong.

Harrison and bates [13] mentioned that the braincase of *Vulpes cana* skull is small and narrow anteriorly and its palate strikingly narrow, these descriptions resemble the Libyan foxes but the palate is not so narrow.

The measurements in *Vulpes ruppelli* skull which has been taken by Harrison [12] indicate that the greatest length of skull 102.0, condylobasal length 97.4, zygomatic breadth 58.4 and interorbital constriction 19.7 mm. These later readings completely different from the results of our work as follows: greatest length of skull 127.1, condylobasal length 125.5, zygomatic breadth 65.1 and interorbital constriction 23.9 mm, these calculations may be due to the differences in the size of foxes that related to their ages.

Many researchers for example Lariviere and Pasitschniak-Arts [25] and Clark et al. [26] noted that the total skull length of corsac foxes was smaller than the red foxes, whose skulls range from 140-150 mm. In other studies for example, Bannikov [44], Dulamtseren [45] and Batsaikhan et al. [30] suggested that skulls greater than 130 mm in length come from red foxes, while skulls less than 130 mm in length come from corsac foxes. Also, Heptner et al. [31] stated that corsac fox skull lengths range between 95 and 112 mm and suggested if the total length of the skull is >115 mm then it comes from a red fox. Study by Munkhzul et al. [29] observed that corsac foxes demonstrated smaller, shorter and wider skulls. On the other hand, Scokolov and Orlov (27) confirmed that the total length of red fox skulls varied between 130 and 160 mm. When comparing the above information to what found in this study, the length skull of these foxes ranged from 112 to 138.5 mm, which is in the middle positions between the corsac foxes and the red foxes.

In a comparison between corsac and red foxes, scientists like Scokolov and Orlov [27], Sheldon [28], Clark et al. [26] and Munkhzul et al. [29] found that the corsac ones have a less-developed sagittal crest, a more gradually tapering rostrum, and smaller, flatter auditory bullae than do red foxes. These mentioned structures in my specimen show more similarities to red foxes.

Munkhzul et al. [29] published that the temporal lines of the postorbital processes of the red fox formed a V-shape on top of the skull; these results are similar to the Libyan foxes which have this V-shape on the top of the skull. Both of the above foxes are different from corsac foxes that their temporal lines ran parallel on the top of the skull.

It is found that the red foxes have an upper side more arched and wide foramen magnum, these results resemble to what found in north Africa *Vulpes ruppelli*, but in the same time these descriptions are different from what they found in corsac foxes whose have a more oval shape foramen magnum [29].

Study by Barison et al. [32] showed that the skull of the Crab-eating fox (*Cerdocyon thous*) was caudally elongated with the larger temporal zygomatic process, this shape is different from what resulted in the present work, but the similarity between the two foxes are the incomplete orbits of the Crab-eating fox that are located in the middle distance between the occipital and nasal bones laterally.

The results in a comparison between the red fox and raccoon dog by Jurgelenas et al. [33] pointed that the double condylar canal in the skull of red fox opens in the ventral condylar fossa, the paracondylar processes extended ventrolaterally and with double ethmoidal foramen. The ventral margin of its foramen magnum takes a V-shape view. These characters resemble to *Vulpes ruppelli* fox and also both of them are similar to our specimens in having a well-developed external sagittal crest at the margin of the interparietal bone.

As record by Karan et al. [35] many carnivores like dogs, badges, and martens, their skull has typical well-articulated zygomatic processes, whereas in cats they extend to the frontal processes of the zygomatic bones, these mentioned processes were studied by Jurgelenas et al. [33] and found them were well developed and directed ventrolaterally in raccoon dog but their direction was laterally only in red fox. These zygomatic processes are similar to what is found in the present work.

Jurgelenas et al. [33] mentioned another part of the skull which is the skeleton of the lower jaw and noted that the mandible of red fox has a flat indentation, the entire surface of ramus was occupies with the masseteric fossa, and the posterior end of mandible formed an angulo-articular hook-shaped process. All the structures that stated about the mandible resemble the sample of *Vulpes ruppelli*.

In comparison between the red fox and corsac fox, Munkhzul et al. [29] observed that both of them have two mental foramina of the mandible and the lower edge of the ramus in the red fox curved gently back to the end of the angle, but in the corsac foxes showed a distinct step, or break, just in front of the angle. The mandible of *Vulpes ruppelli* has the same structures in its mandible. The dental formula of *Vulpes ruppelli* that has been identified as I 3/3, C 1/1, P 4/4, M 2/3, total 42 by Harrison [12] and Rosevear [6]. It is quite similar to what is found in this study.

5. CONCLUSIONS

The results of this research fill a wide gap of information in the cranial skeleton of Libyan *Vulpes rueppelli* fox that was not available in the past. This study showed here and for the first time, the articulation and the precise structures of external and internal bones that involved in the skull of the mentioned fox.

6. REFERENCES

1. George C, Kent. Comparative anatomy of the vertebrates, Third edition Department of Zoology. Baton Rouge, Louisiana, Saint Louis. Louisiana State University. 1973.
2. Sillero-Zubiri C, Hoffmann M, Macdonald DW. Status Survey and Conservation Action Plan—Canids: foxes, wolves, jackals and dogs. Gland, Cambridge (IUCN/SSC Canid Specialist Group). 2004.
3. IUCN. Red list of threatened species. International Union for Conservation of Nature and Natural Resources, Gland, Switzerland. 2006.
4. Ellerman J, Morrison-Scott T. Checklist of Palaearctic and Indian Mammals British Museum (Natural History). 1966:1758-1946
5. Hüfnagl E. Lybian mammals. The Olander Press, New York. 1972.
6. Rosevear DR. The carnivores of West Africa. The British Museum (Natural History) London: publication number. 1974;8:723,ISBN 0565 00723.
7. Qumsiyeh MB. Mammals of the Holy Land. Texas Tech University Press. 1996.
8. Kowalski K, Rzebik-Kowalska B. MammalsofAlgeria. Polish Academy of Sciences, Institute of Systematics and evolution of Mammals, Krakow, Poland. 1991.
9. Geraads D. Carnivores du Pliocene terminal de Ahl al Oughlam (Casablanca, Maroc). Geobios. 1997;30(1):127-164.
10. Geffen E, Mercure A, Girman DJ, Macdonald DW, Wayne RK. Phylogenetic relationships of the foxlike canids: mitochondrial DNA restriction, site and cytochrome b sequence analysis. Journal of Zoology. 1992;228(1):27-39.
11. Brock J, Corbet GB, Hills M. Review of the family Canidae, with a classification by numerical methods. Bull Br Mus Nat Hist Zool. 1976.

12. Harrison DL. The mammals of Arabia: Carnivora, Artiodactyla, Hyracoidea. Ernest Benn Limited, London. 1968;2:1-381.
13. Harrison DL, Bates PJ. Observations on two mammal species new to the Sultanate of Oman, Vulpes cana Blanford, 1877 (Carnivora: Canidae) and Nycteris thebaica Geoffroy, 1818 (Chiroptera: Nycteridae). Bonner Zoologische Beitraege. 1989;40:73-77.
14. Kolb HH, Hewson R. The body size of the red fox (Vulpes vulpes) in Scotland. Journal of Zoology. 1974;173(2):253-255.
15. Lups P, Wandeler AI. Metrische Untersuchungen an Füchsen (Vulpes vulpes L.) aus dem Schweizerischen Milleland. Zoologischer Anzeiger. 1983;211(5-6):285-298.
16. Wandeler AI, Lups P. Vulpes vulpes (Linnaeus, 1758) – Rotfuchs. In: Stubbe M. & Krapp F. (eds.), Handbuch der Säugetiere Europas, Vol. 1. Aula-Verlag, Wiesbaden. 1993.
17. Macdonald DW, Sillero-Zubiri C. Wild canids – an introduction and dramatic personae. In: Macdonald, D. W., Siller-Zubiri, C (eds). Biology and Conservation of Wild Canids. Oxford. 2004:3-36.
18. Churcher CS. Cranial variation in the north American red fox. Journal of Mammalogy. 1960;41(3):349-360.
19. Huson LW, Page RJ. A comparison of fox skulls from Wales and south-east England. Journal of Zoology. 1979;187(4):465–470.
20. Fairley JS, Bruton T. Some observations on a collection of fox skulls from north-east Ireland. The Irish Naturalists' Journal. 1984;21(8):349-351.
21. Hell P, Paule L, Sevcenko LS, Danko S, Panigaj L. Craniometrical investigation of the red fox (Vulpes vulpes) from the Slovak Carpathians and adjacent lowlands. Folia zoologica (Brno). 1989;38(2):139-155.
22. Ansorge H. 1994. Intrapopular skull variability in the red fox, Vulpes vulpes (Mammalia: Carnivora: Canidae). Zoologische Abhandlungen, Staatliches Museum Fur Tierkunde Dresden. 1994;6:103-123.
23. Lynch JM. Sexual dimorphism in cranial size and shape among red foxes Vulpes vulpes from north-east Ireland. In Biology and Environment: Proceedings of the Royal Irish Academy. 1996;96:21-26.
24. Demuth J, Hromada M, Krawczyk A, Malecha A, Tobolka M, Tryjanowski P. Cranial lesions caused by helminth parasites and morphological traits in the European polecat Mustela putorius. Helminthologia. 2009;46(2):85-89.
25. Lariviere S, Pasitschiniak-Arts M. Vulpes vulpes. Mammalian Species. 1996;537:1-11.
26. Clark HO, Murdoch JD, Newman DP, Sillero-Zubiri C. Vulpes corsac (Carnivora: Canidae). Mammalian Species. 2009;832:1-8.
27. Sokolov BE, Orlov BN. Identification Key to the Mammals of the Mongolian People's Republc. Moscow. 1980:200-204.
28. Sheldon JW. Wild dogs. The natural history of the nondomestic Canidae. Blackburn Press, Caldwell, New Jersey. 1992.
29. Munkhzul T, Reading RP, Buuveibaatar B, Murdoch JD. Comparative craniometric measurements of two sympatric species of Vulpes in Ikh Nart Nature Reserve, Mongolia. Mongolian Journal of Biological Sciences. 2018;16(1):19-28.
30. Batsaikhan N, Samiya R, Shar S, Lkhagvasuren D, King SR. A Field Guide to the Mammals of Mongolia. Ulaanbaatar. 2014:222-224.
31. Heptner VG, Naumov NP, Yurgenson PB, Sludskiy AA, Chirk-ova AF, Bannikov AG. Mammals of the USSR. Moscow. 1992:270-410.
32. Barisson JD, Louro CH, Dias SJ, Jojima FS, Ferreira MS, Oliveira FS. Anatomo-radiographic description of the axial skeleton of the crab-eating fox (Cerdocyon thous). Pesquisa Veterinária Brasileira. 2012;32:01-03.
33. Jurgelėnas E, Daugnora L, Monastyreckienė E, Balčiauskas L. On the skull morphology of raccoon dog (Nyctereutes procyonoides) and red fox (Vulpes vulpes). Acta Zoologica Lituanica. 2007;17(1):41-46.
34. Frackowiak H, Nabzdyk M, Kulawik M, Przysiecki P, Nowicki S. Comparative craniometry and skull morphology of red fox (Vulpes vulpes) and arctic fox (Vulpes lagopus). Nauka Przyroda Technologie. 2013;7(3):42-56.
35. Karan M, Tımurkaan S, ÖZdemır D, Ünsaldi E. Comparative macroanatomical study of the neurocranium in some carnivora. Anatomia, histologia, embryologia. 2006;35(1):53-56.
36. Fike JR, LeCoutur RA, Cann CE. Anatomy of thc canine orbital region. Multiplanar Imaging by CT. Veterinary Radiology. 1984;25(l):32-36.
37. Endo H, Obara I, Yoshida T, Kurohmaru M, Hayashi Y, Suzuki N. Osteometrical and CT examination of the Japanese wolf skull. Journal of veterinary medical science. 1997;59(7):531-538.
38. Yilmaz S, Dinç G, Toprak B. Macro-anatomical investigations on skeletons of otter (Lutra lutra). III. Skeleton axiale. Department of Anatomy, Faculty of Veterinary Medicine, Firat University, Elazig, Turkey. 2000;70(4):191-198.
39. Kuru M. Omurgali Hayvanlar. Atatürk Üniv. Basimevi. Erzurum. 1987:577-580.
40. Demirsoy A. Yasamin temel kurallari. Meteksan Anonim Sirketi. Ankara. 1992:759-760.
41. Wozencraft WC. "Order Carnivora". In Wilson, D.E.; Reeder, D.M. Mammal Species of the World: A Taxonomic and Geographic Reference (3rd ed.). Johns Hopkins University Press. ISBN 978-0-8018-8221-0. OCLC 62265494. 2005:532–628.
42. Gasperetti J, Harrison DL, Buettiker W. The Carnivora of Arabia. Fauna of Saudi Arabia. 1985;7:397-413.
43. Stephen P, Nawrocki Ph.D., D.A.B.F.A. Clening bones. University of Indianapolis Archeology & Forensics Laboratory, Indianapolis, Indiana, U.S. 1997.
44. Bannikov AG. Mammals of the Mongolian People's Republic.-Moscow. 1954.
45. Dulamtseren S. Identification Key to the Mammals of the Mongolia. Ulaanbaatar. 1970:32-38,137-140.

List of Abbreviations

Abbreviations	Meaning	Abbreviations	Meaning
AP	Angular process	Pe	Periotic
AS	Alisphenoid bone	PgF	Postglenoid foramen
AuB	Auditory bulla	Pl	Palatine bone
BO	Basi-occipital bone	PM	Process of maxilla
BS	Basisphenoid bone	PoPPF	Posterior opening of posterior palatine foramen
C	Canine	PPF	Posterior palatine foramen
CaF	Carotid foramen	PPr	Process of premaxilla
Cf	Coronoid fossa	Pr	Premaxilla bone
Co	Condyle	PrMo	Premolar
CP	Coronoid process	PrS	Presphenoid bone
D	Dentary	Pt	Pterygoid bone
E	Ethmoid complex	S	Sphenoid bones
ExO	Exoccipital bone	Sc	Sagittal crest
F	Frontal bone	SF	Sphenopalatine foramen
FiOF	First optic foramen	SO	Supra-occipital
FM	Foramen magnum	SOF	Second optic foramen
FOF	Fourth optic foramen	Sq	Squamosal bone
I	Incisor	T	Turbinals
IF	Incisive foramina	TOF	Third optic foramen
IOF	Infraorbital foramen	V	Vomer
J	Jugal bone	XS	Xiphisternum
JF	Jugular foramen	Z	Zygomatic arch
L	Lachrymal bone		
LF	Lachrymal foramen		
M	Maxilla bone		
Ma	Mandible		
MaF	Mandibular foramen		
MeF	Mental foramen		
Mo	Molar		
Mt	Meatus		
N	Nasal bone		
O	Occipital bones		
OC	Occipital condyle		
OF	Optic foramina		
OS	Orbitosphenoid bone		
P	Parietal bone		