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Macro-anatomical investigations on the skeletons of mole-rat (*Spalax leucodon* Nordmann) III. Skeleton axiale

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ABSTRACT

The average length and height of the skull were 42.5 mm and 15.7 mm, respectively. The height of the skull was approximately 37% of the length of the skull in mole-rats (*Spalax leucodon* Nordmann). The average greatest breadth and the greatest height of the for. magnum were 6.9 mm and 6.1 mm, respectively. The dental formula on one half of the upper and lower jaw was I1, C0, P0, M3 / I1, C0, P0, M3. Arcus zygomaticus was well developed and formed by the proc. zygomaticus of os temporale, the proc. temporalis of os zygomaticum and a third small bone (jugal). The third bone was not fused with the other processes forming the arcus zygomaticus. The two halves of the mandibula were not fused. There were four processes of the ramus mandibulae: proc. angularis, proc. coronoideus, proc. condylaris and the fourth process lodging the lower incisor tooth. The vertebral formula was found as C7, T13, L6, S4, Ca5. Cranial articular processes of the first caudal vertebrae were present. There were rudimentary cranial articular processes on the second caudal vertebrae and cranial articular processes were absent on all other caudal vertebrae. Caudal articular processes were not present on all caudal vertebrae.

Key words: axial skeleton, *Spalax leucodon* Nordmann, mole-rat

Introduction

Mole-rats belong to the Spalacidae family, order Rodentia. They are subterranean rodents and live in their own tunnel system. They spend their whole life under ground and only rarely appear above ground (VINOGRADOV and ARGIROPULO, 1941). They are mainly phytophagous animals and inhabit by burrowing in soft and productive agricultural plants, steppes and gardens (DEMİRSOY, 1997). These animals use their extremities for burrowing and shovelling and they are often confused with moles (*Talpa europaea* Linnaeus) (DEMİRSOY, 1997; DEMİRSOY, 1998; KURU, 1999). The literature on

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the macro-anatomical features of the skeletal system in mole-rats is meager. There are many macro-anatomical investigations on the skeletal system of mammals, including the rabbit, the guinea pig, the rat (ÖZKAN et al., 1997), the mink (DURSUN and TIPIRDAMAZ, 1989), the badger (HIDAKA et al., 1998; DINÇ, 2001) the porcupine (YILMAZ, 1998), the hedgehog (ÖZKAN, 2005), but the skeletal systems of mole-ratshave not been investigated in detail.

The aim of the present study was to investigate the axial skeleton in mole-rats and to contribute to information in this field.

Materials and methods

Examined bones were obtained from five adult male mole-rats with an average body mass of 180 gr and a body length of 22 cm inhabiting their own tunnels in plantations in Elazığ. Maceration of bones was carried out by the method of (TAŞBAŞ and TECIRLIOĞLU, 1966). Skull measurements were taken using the method of (VINOGRADOV and ARGIROPULO, 1941). Nomina Anatomica Veterinaria (1994) was used for terminology. Abbreviations: for.: foramen, proc.: processus.

Results

Ossa cranii. A significant nuchal crest lying horizontally at the caudal border of the os parietale was present and crista sagittalis externa, lying from the horizontal crest to the anterior 2/3 of the os frontale, was prominent (Fig. 1). There were two supracondylar foramina on the fossa condylaris dorsalis. Fossa condylaris ventralis was deeper than the fossa condylaris dorsalis. The intercondyloid notch was significant. Canalis n. hypoglossi was present. The nuchal planum was broad and there was no crista occipitalis externa. There was a distinct fossa on the ventral face of pars basilaris of os occipitale. The average greatest breadth and greatest height of the for. magnum were 6.9 mm and 6.1 mm, respectively. There was no arcus on the orbita and the orbita was broadly continuous with the temporal fossa. For. supraorbitale was absent. The bulla tympanica of the pars endotymponica of the os temporale was well developed and there was a small, ventromedially directed spinous process on the medial border of this bulla, and on the caudal border there was a medially directed process near the proc. jugularis. Average greatest breadth and greatest height of the porus acusticus externus on the bulla tympanica were 2.7 mm and 2.3 mm, respectively.

The end of proc. pterygoideus of os basisphenoidale was dorsally curved. Average length and height of the skull were 42.5 mm and 15.7 mm, respectively, and height of the skull was approximately 37% of the length of the skull in mole-rats (Table 1).

Table 1. Measurements of the skull in mole-rats. Average, mm.

Length of skull From the most anterior part of the maxillaries to the posterior surface of the occipital condyles	42.5
Length of cranial region From the posterior side of the alveolus of the last molar to the occipital condyles	16.3
Interorbital width The narrowest space between the orbits	7.1
Length of nasal region (diastema) Measured from the posterior side of the base of the upper incisors to the base of the first molar	15.6
Length of diestema the lower jaw Measured from the posterior side of the base of the lower incisors to the base of the first molar	5.2
Length of row of lower jaw molars Alveolar length-measured from the bases of the teeth at each end of the row	7.4
Length of row of upper jaw molars Alveolar length: measured from the bases of the teeth at each end of the row	7.3
Zygomatic width The distance between the outer sides of the zygomatic arches farthest from the skull	30.1
Maximum height of skull Measured from the heighest point of the skull in the parietal region to the lowest point of the tympanic bullae	15.7

Ossa faciei. Arcus zygomaticus was well developed and formed by the proc. zygomaticus of os temporale, the proc. temporalis of os zygomaticum and a third small bone (jugal) (Fig. 1). The third bone was not fused with the other processes forming the arcus zygomaticus. The proc. temporalis of os zygomaticum was longer than the proc. zygomaticus of os temporale. There was a shallow fossa on the craniodorsal part of the for. infraorbitale and a slightly prominent crest was present between this fossa and the for. Infraorbitale. A maxillar crest cranially bordering this fossa was present. The for. infraorbitale was significantly larger, and the average greatest breadth and greatest height of this foramen were 4.6 mm and 3.1 mm, respectively. The dental formula on one half of the upper jaw was I1, CO, PO, M3.

The for. palatinum majus and foramina palatina minora were absent on the lamina horizontalis of os palatinum, and a significant crest lying sagittally and two longitudinal grooves on the ventral face of the os palatinum were present. The nasal bones were slightly

convex and anterior portion was wider than posterior portion; approximately anterior 1/4 of these bones were fused. The dental formula on one half of the lower jaw was I1, CO, PO, M3. The two halves of the mandibula were not fused. There were four processes of the ramus mandibulae. The proc. angularis of the ramus mandibulae was significant and caudolaterally directed. The proc. coronoideus had a tapering and caudodorsally directed end. Incisura mandibulae was significant and the end of caudodorsally directed proc. condylaris was convex and larger than the proc. Coronoideus; the level of proc. coronoideus was higher than the proc. condylaris. The fourth process was coudolaterally directed and the lower part of the incisor tooth was lodged into this process (Fig. 1). The fossa masseterica was shallow and the for. mandibula was on the medial surface at the base of the proc. condylaris. The small for. mentale was on the distal of first molar alveolus.

Fig. 1. General view of a mole-rat's skull. 1) the nuchal crest; 2) crista sagittalis externa; 3) the small third (jugal) bone; 4) for. infraorbitale. Arrow: the opening between the temporal and zygomatic processes. The small third (jugal) bone was removed.

Vertebrae cervicales. Atlas - for. transversarium and for. alare were present, and there was no incisura alaris. Proc. transversus was small. Fossa atlantis was significant. There was a rathetr distinct longitudinal groove on the arcus dorsalis and a caudally directed spinous process on the arcus ventralis.

Axis. The caudodorsally directed spinous process of axis was thicker and higher than the spinous processes of the other cervical vertebrae and there was a deep groove on the caudal face of the spinous process.

Third-seventh vertebrae cervicales. There were no ventral tubercles on eithzer of the ventral surfaces of the bodies of the vertebrae cervicales. The spinous processes of the axis and the 3rd and 4th vertebrae cervicales were caudodorsally directed; the 6th and 7th vertebrae cervicales were craniodorsally directed, and the 5th cervical vertebra was dorsally directed. The small transverse processes of the 2nd, 3rd and 4th cervical vertebrae were caudolaterally directed, and the 5th, 6th and 7th cervical vertebrae were laterally directed. The caudal end of the proc. costalis of the proc. transversus of the 6th cervical vertebra was pointed. Fovea costalis caudalis was present on the 7th cervical vertebra.

Vertebrae thoracicae. There were 13 thoracic vertebrae. The caudal ends of the transverse processes were caudolaterally directed. Incisura vertebralis caudalis was deeper than incisura vertebralis cranialis; for. vertebrale laterale was absent. Fovea costalis caudalis was more distinct than fovea costalis cranialis. Spinous processes of the thoracic vertebrae were caudodorsally inclined, and the dorsal processes of the last two thoracic vertebrae were wide and dorsally projected.

Vertebrae lumbales. There were 6 lumbal vertebrae. The level of the spinous processes was the same on both lumbal vertebrae. The ventral crest was present only on the last two lumbal vertebrae. The transverse processes of the 3rd, 4th and 5th lumbal vertebrae were larger than the other lumbal vertebrae. The tranverse process of the last lumbal vertebra was craniolaterally directed. The vertebrae lumbales were slightly larger than the vertebrae thoracicae from the dorsal view.

Vertebrae sacrales. Os sacrum was composed of 4 sacral vertebrae. The spinous processes of both sacral vertebrae were fused and both of the transverse processes were fused to form pars lateralis. The first sacral vertebra was significantly larger than the other sacral vertebrae. Facies pelvina was slightly concave. There was one pair of foramina sacralia dorsalia and three pairs of foramina sacralia ventralia.

Vertebrae caudales. There were 5 caudal vertebrae articulated with their bodies. Cranial articular processes of the first caudal vertebrae were present. There were rudimentary cranial articular processes on the second caudal vertebrae and cranial articular processes were absent on all other caudal vertebrae. Caudal articular processes were not present on all caudal vertebrae. The transverse processes were present on the first three caudal vertebrae.

Costae. There were 13 pairs of ribs. The first eight pairs were sternal (costae verae), 3 pairs were asternal (costae spuriae) and the last 2 pairs were floating ribs (costae fluctuantes). There was a distinct costal groove on the external faces of the bodies of the 3rd, 4th and 5th ribs. The second rib had a faint groove and there were no costal grooves on the bodies of other ribs. The bodies of the first five ribs were flat, while the bodies of the other ribs were cylindrical.

Sternum. The sternum was composed of deltoid-shaped manubrium sterni, five sternebrae and slender proc. xiphoideus. Both of the sternebrae bodies were cylindrical. The longest sternebra was the second and the shortest was the fifth sternebra (Fig. 2).

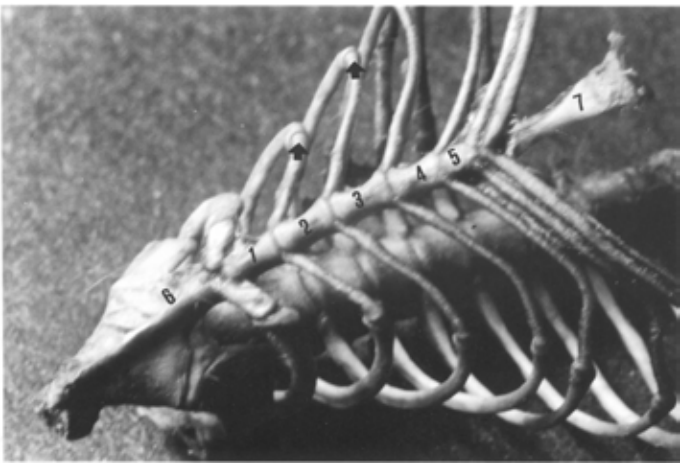

Fig. 2. The skeleton thoracis in the mole-rat, ventral view. 1-5) sternebrae; 6) manubrium sterni; 7) proc. xiphoideus. Arrow: genu costa.

Discussion

The dental formula in mole-rats is I1, C0, P0, M3 (upper row) / I1, CO, PO, M3) lower row) (DEMİRSOY, 1998), in moles is I3, C1, P4, M3 (upper row) / I3, C1, P4, M3 (lower row) (SAUNDERS and MANTON, 1969) and I2-3, C1, P3-4, M3 (upper row) /I1-2, CO-1, P3-4, M3 (lower row) and the first upper incisors are inclined backward (VAUGHAN, 1972). The incisors of Rodentia have a characteristic chisel-shaped form, and lack roots (VINOGRADOV and ARGIROPULO, 1941). Canine and premolar teeth are absent in the order Rodentia and hence there are large vacancies in the jaws (KURU, 1999). In some rodent species, premolar teeth are present (DEMİRSOY, 1997) but premolars are absent in mole-rats (VINOGRADOV and ARGIROPULO, 1941). In the dentition of the rodent skull, there are never any canine teeth and there is a wide gap or diastema between the incisors and the cheek teeth (SAUNDERS and MANTON, 1969). In the present study it was observed that there were no canine and premolar teeth in the upper and lower jaw in mole-rats. The upper incisors were dorsoventrally directed and the lower incisors were craniodorsally inclined. The dental formula was found to be I1, CO, PO, M3 (upper row) / I1, CO, PO, M3 (lower row) in mole-rats, as stated by (DEMIRSOY, 1998). There were large vacancies in the jaws as reported in the Rodentia (KURU, 1999) but the vacancy in the upper jaw was

greater than that in the lower jaw. The average distance of the *diastema* in the upper jaw 15.6 mm, and in the lower jaw 5.2 mm (Table 1).

Length of skull is up to 40 mm as a small form in mole-rats (*Spalax leucodon* Nordmann) (VINOGRADOV and ARGIROPULO, 1941) and in moles (DEMIRSOY, 1998). Height of skull is 16-21 mm in mole-rats (*Spalax leucodon* Nordmann) (VINOGRADOV and ARGIROPULO, 1941) and in the skull of the rat the height is appreciably less than one-third of the total length (DUBRUL, 1950). In our study, average length and height of skull were 42.5 mm and 15.7 mm, respectively; height of the skull was approximately 37% of the length of the skull in mole-rats.

Arcus zygomaticus is narrow and flexed to the inferior in mole-rats (DEMIRSOY, 1998). In the skulls of moles, the zygomatic arch is often incomplete and the jugal may be small or absent (SAUNDERS and MANTON, 1969). The small jugal is present in the Rodentia (VINOGRADOV and ARGIROPULO, 1941; WELLS, 1964). Arcus zygomaticus is not complete in many species of the order Insectivora (ÖKTAY, 1988) but in moles it is complete (VAUGHAN, 1972). In the current study, arcus zygomaticus was well developed and composed of proc. zygomaticus of os temporale, the proc. temporalis of os zygomaticum and a third small jugal bone. In the skulls of moles there is usually no bulla (SAUNDERS and MANTON, 1969) and the tympanic cavity is not fully enclosed by bone (VAUGHAN, 1972). In this study, a well developed bulla tympanica was identified in mole-rats. The skulls of adult rodents often bear crests (VINOGRADOV and ARGIROPULO, 1941). Similarly, a significant nuchal crest lying horizontally, and the crista sagittalis externa, were prominent. There was a broad occipital area on the posterior side of nuchal crest in mole-rats, as reported in Rodentia (VINOGRADOV and ARGIROPULO, 1941). The for. infraorbitale was large in mole-rats, as reported in Rodentia (VINOGRADOV and ARGIROPULO, 1941) and the average greatest breadth and greatest height of this foramen were 4.6 mm and 3.1 mm, respectively. The nasal bones were narrowed posteriorly in mole-rats, as reported in moles (SAUNDERS and MANTON, 1969).

In the skulls of moles, the lower jaw has a peculiarly shaped hinder border (SAUNDERS and MANTON, 1969). Similarly, in mole-rats there are four processes of the ramus mandibulae. These processes were the proc. angularis, proc. coronoideus, proc. condylaris and the fourth process lodging the incisor tooth. In the mandibular skeleton of the rat, the coronoid processes are relatively large and both condyles project posterosuperiorly as distinct entities (MOSS, 1968). In the present study, the proc. condylaris was larger than proc. coronoideus, and proc. condylaris was caudodorsally directed in mole-rats. In mole-rats, the transit portion from the proc. condylaris to the proc. angularis was significantly curved, while it is linear in badgers (HIDAKA et al., 1998).

The vertebral formula was reported as C7, T13, L6, S4, Ca6 in the Spalacidae family, order Rodentia (LESSERTISSEUR and SABAN, 1967). In our study, it was observed to be

C7, T13, L6, S4, Ca5 in mole-rats. In the rat, the major axes of vertebral column and skull are roughly in the same horizontal line (DUBRUL, 1950). Similar results were observed in mole-rats. The body of the sternum consists of five sternebrae in the mink (DURSUN and TIPIRDAMAZ, 1989), six sternebrae in the porcupine (YILMAZ, 1998), and eight sternebrae in the badger (DINÇ, 2001). In the current study, five sternebrae were found in mole-rats. Mammalian sacrals are generally three to five in number (ROMER and PARSONS, 1978). In Insectivora, sacral conditions vary widely and in moles the vertebrae are firmly fused (SAUNDERS and MANTON, 1969; YOUNG, 1962). In our study, os sacrum was composed of 4 sacral vertebrae. The spinous processes of both sacral vertebrae were fused and both transverse processes were fused to form pars lateralis in mole-rats.

In conclusion, some prominently different or similar features from other rodents and insectivors in the axial skeleton in mole-rats were noted, which contributes to information in this field. In particular, the jugal bone stated as small or absent in moles was the third bone forming the zygomathic arch in mole-rats. The bulla usually stated as being absent in the skulls of moles was well developed in mole- rats. Similarly, the sacral vertebrae were fused in mole-rats, as in moles.

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SAŽETAK

Prosječna dužina lubanje bjelozuboga sljepaša (*Spalax leucodon* Nordmann) iznosila je 42,5 mm, a visina 15,7 mm. Visina lubanje bila je približno 37% veća u odnosu na njezinu dužinu. Prosječna najveća širina velikoga zatiljnoga otvora (foramen occipitale magnum) bila je 6,9 mm, a njegova prosječna najveća visina bila je 6,1 mm. Sastav zubala na jednoj polovici gornje i donje čeljusti bio je I1, C0, P0, M3 / I1, C0, P0, M3. Jagodični luk bio je dobro razvijen te oblikovan od jagodičnog izdanka sljepoočne kosti, sljepoočnog izdanka jagodične kosti te treće male kosti (jugularnog izdanka). Treća kost nije srasla s ostalim izdancima te ne tvori jagodični luk. Dvije polovice donje čeljusti nisu srasle. Postoje četiri izdanka donjočeljustne grane: kutni izdanak, vjenčasti izdanak, kondilarni izdanak te četvrti izdanak koji nosi donji sjekutić. Broj kralježaka iznosio je C7, Th13, L6, S4, Ca5. U štakora je utvrđen i kranijalni zglobni izdanak prvoga repnoga kralješka. Postoje i rudimentarni kranijalni zglobni izdanci na drugom repnom kralješku. Kranijalni zglobni izdanci izostali su na svim ostalim repnim kralješcima. Na repnim se kralješcima ne nalaze zglobni izdanci.

Ključne riječi: osovinski kostur, *Spalax leucodon* Nordmann, bjelozubi sljepaš