

## Examining neurocranial development in Iraqi indigenous sheep (*Ovis aries*): An osteomorphometric study

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### Article information

#### Article history:

Received 07 January, 2025  
Accepted 01 May, 2025  
Published 08 November, 2025

#### Keywords:

Fetuses  
Morphometry  
Neurocranium  
Sheep

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### Abstract

The skull is a collection of symmetrical and asymmetrical bones that protect the brain and house the sensory organs. The skull's shape defines the head's structure, which is closely linked to various physical and phenotypic characteristics usually used to classify and typify diverse strains of animals, their genomic profiles, and their association with close atmosphere. This work aims to define the osteomorphometrical parameters of the neurocranium, skull base, and cranial cavity capacity (CCC) using 48 Iraqi domestic sheep fetuses at 50-155 days of gestation, measured using electronic Vernier and measurement tape. The fetuses' skulls were prepared by maceration using NaOH. CCC was obtained by filling it with mustard seeds through the foramen magnum. Thirty-two osteomorphometrical parameters were measured within the dorsal, lateral, and ventral surfaces. The work showed significant differences in skull length and width at 7-15 weeks of pregnancy, and the correlation between the cranial cavity capacity was very strong and positive with all variables. While the width of the foramen magnum increases significantly with progressive the pregnancy. The foramen magnum index showed a downward trend from the period 7-11 weeks, then an upward trend from the period 12-16 weeks, then a downward trend again from the period 17-19 weeks, where it appeared almost oval. A weak correlation between the orbital index and the total length variable, and the orbital cavity took an almost circular shape. Skull measurements can be used in breeding programs to improve desired traits, achieve specific production goals, and help identify animals with superior genetic traits.

DOI: [10.33899/ijvs.2025.156382.4078](https://doi.org/10.33899/ijvs.2025.156382.4078). ©Authors, 2025, College of Veterinary Medicine, University of Mosul.  
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### Introduction

Iraqi sheep are known for their coarse wool and a broad tail full of fatty matter. In recent years, the average sheep population in Iraq has been approximately 8 million. They are divided into three main breeds, namely Awassi sheep, Kurdish sheep, and Arab sheep, and have been exposed over the years and for long periods to harsh environmental conditions such as drought, food shortages, and diseases. This adaptation to challenging conditions has come at the expense of their distinctive economic traits (1). The bones of the neural cranium are derived primarily from the neural crest and paraxial mesoderm (2-4). Depending on the origin and

type of bone growth, the bones of the skull are classified into two main categories: the neurocranium and the viscerocranium. The neurocranium consists of two parts: the membranous part, consisting of flat bones that form the protective vault around the brain, and the cartilaginous part consists of the bones of the base of the skull (5,6). The skull is a collection of thin bones that are comparatively flat and shelter the brain and distinctive intellectual structures in lacrimal, nasal, acoustic, and lingual areas. The profile of the head is subject to the skull and is strictly interrelated to definite physical topographies (7). These physical and phenotypic topographies were universally used to categorize and describe diverse strains of animals, their hereditary

profiles, and their association with the nearby atmosphere (8). Skull measurements are critical for diagnosing deformities, determining sex, and addressing clinical issues. Sexual dimorphism is intensely demonstrated in the head skeleton of the ruminants (9). Studies conducted on cranial bones have significantly contributed to taxonomy, functional anatomy (10-13) and in the experimental veterinary training, surgery, implantology, stereotaxic applies, animal health, etc. (14,15). Maceration is an important technique for visualizing the morphometric component of the bones, and for this reason, it is considered (16). Different maceration techniques rely on removing soft tissues attached to the bone structures. The most common maceration techniques use inorganic chemicals and insects (17). Bone radiography readings perform an original character in new scientific medication. The readings focus on medicinal law, archaeozoology, and the features of bone development. X-ray readings of the cranium are a significant instrument in the field of anatomy for investigative determinations in humans and animals (18). Danmaigoro *et al.* (19) assessed the development of hind limb bones in Sokoto red goat fetuses during the three stages of gestation using a combination of techniques. Hena (18) accompanied X-ray readings on the craniums of 32 fetuses of the one-humped camel (*Dromedarius Camelus*): 11 fetuses in the third trimester of pregnancy, 12 fetuses in the second trimester, and 9 fetuses in the first trimester of pregnancy for evaluation of the cranium development. Pacheco *et al.* (20) described the ossification pattern in alpacas using radiographic methods, involving 17 pregnant alpacas from which embryos of various gestational ages were collected (45, 60, 90, 118, 150, 165, 190, 220 and 280 days). Numerous studies have examined the morphometrics of cranial bones across various species, including dogs (21), cat (7), goat (22-27), horse (28), sheep (29) and Iranian cattle and dromedary camel (30-32) to provide standard anatomical data. The cranium has also been used as a main skeletal construction to define taxonomic relationships as it is a theme of phenotypic variations due to choosy breeding (33).

There is a notable lack of research on the cranial morphometry of developing sheep in Iraq; therefore, the current reading designed to examine morphometrical parameters of the cranium of sheep fetuses in Iraq, thus causal in substantial the hole of information in the field of gross and applied anatomy and construction works valuable to the field veterinarians in addition to zoo veterinarians.

## Materials and methods

### Ethical approval

The ethical permission was approved by the Institutional Animal Care and Use Committee of the College of Veterinary Medicine, University of Mosul, Mosul, Iraq, which had NO.: UM.VET.2023.082.

### Preparation of samples and ethical approval documentation

Forty-eight Iraqi domestic sheep fetuses were obtained from Mosul city abattoir from the summer of 2023 to the end of winter of 2024. The possible age in days was calculated as defined by Arthur *et al.* (34) and Sivachelvan *et al.* (35) using Richardson's formulation: Probable age (in days) = 2.1 (17+ crown-rump length (cm)). This crown-rump length is determined by the coronal rim of the frontal bone and alongside the vertebral column to the tail root (Figure 1A). In the present study, the possible age of the domestic sheep fetuses extended from 50 to 155 days, and the crown-rump length extended from 7 to 57 cm. Skulls were prepared using a combination of techniques. These are maceration with sodium hydroxide (NaOH) 2-8% depending on the possible age of the sheep fetus (Figure 1B). In addition, radiography is also used (Figure 1C) (18,36-40).

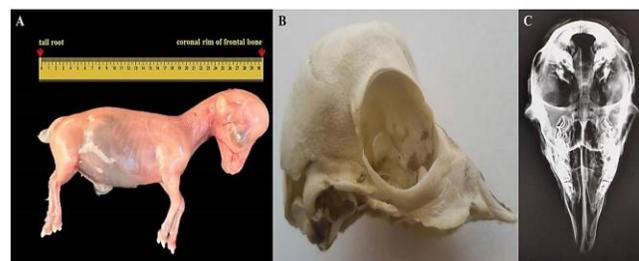


Figure 1: A: a macrophotography showing how to estimate the probable age of the fetus by determining the crown-rump length. B: showing skull of indigenous sheep fetus at 75 days of pregnancy prepared by maceration with NaOH solution (lateral view (right side)). C: radiography of the skull of an Indigenous sheep fetus, aged 147 days of pregnancy (dorsal view).

### Osteomorphometrical measurements

The skull was weighed after excluding mandibles (41-43) using Sartorius balance (EK-I-EW-I, Japan). Thirty-two osteomorphometrical measurements were taken on the dorsal, lateral, and ventral surfaces using electronic Vernier and measurement tape as shown in (Figure 2).

### Dorsal surface measurements

A-Total skull length (TSL)/ Dorsally: The distance from the middle point of the rostral border of the incisive bone to the middle point of the occipital crest (44). B-Total skull width (TSW)/ Dorsally: The distance between the middle points of the zygomatic arches (44). C-The distance between the two supraorbital foramina (DSOF): The distance between the right and left supraorbital foramina (26-27). D-Length of the neurocranium (LNC)/ Dorsally: The distance between the center point of the frontonasal suture to the center point of the occipital crest (41). E-Width of the neurocranium (WNC)/ Dorsally: The distance from the middle point of the

dorso-caudally margin of the right orbit to the middle point of the dorso-caudally margin of the left orbit (45). F-Length of the frontal bone (LFB): The distance from the middle point of the naso-frontal suture to the middle point of the fronto-parietal suture (26-27). G-Width of the frontal bone (WFB): The distance from the end of the lateral rim of the right orbit to the end of the lateral rim of the left orbit (26-27). H-Length of parietal bone (LPB): The distance from the middle point of the frontal-parietal suture to the middle point of the parietal-occipital suture (26-27). I-Width of parietal bone (WPB): The distance from the middle point of the right temporal-parietal suture to the middle point of the left temporal-parietal suture (26-27). J-Length of squamous part of occipital bone (LSPOB): The distance from the middle point of the parietal-occipital suture to the middle point of the occipital crest (26-27). K-Width of squamous part of occipital bone (WSPOB): The distance from the middle point of the right occipital suture to the middle point of the left occipital suture (26-27). L-Skull index/ Dorsally. Skull index = total skull width (dorsally) / total skull length (dorsally) \* 100 (44).

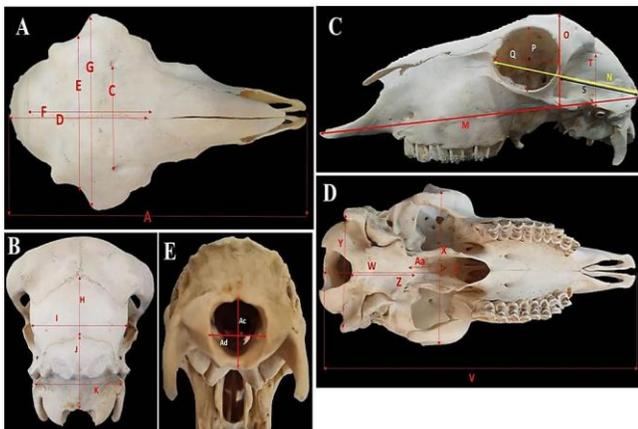


Figure 2: A: a macrophotography of a local sheep skull (dorsal view) showing anatomical measurements. A- Total skull length (dorsally). C- Distance between the supraorbital foramen. D- Length of the neurocranium (dorsally). E- Width of the neurocranium (dorsally). F- Length of the frontal bone. G- Width of the frontal bone. B: a macrophotography of a local sheep skull (occipital view) showing the anatomical measurements. H- Length of the parietal bone. I- Width of the parietal bone. J- Length of the squamous part of the occipital bone. K- Width of the squamous part of the occipital bone. C: a macrophotography of a local sheep skull (Lateral view) showing the anatomical measurements. M- Total skull length (laterally). N- Length of the neurocranium (lateral). O- Width of the neurocranium (lateral). P- Orbital length. Q- Orbital width. S- Length of the temporal bone. T- Width of the temporal bone. D: a macrophotography of a local sheep skull (Lateral view) showing the anatomical measurements. V- Total skull length

(ventrally). W- Length of the skull base. X- Width of the skull base. Y- Distance between the two jugular processes. Z- Length of the basal part of the occipital bone. Aa- Length of the sphenoid bone. E: a macrophotography of a local sheep skull (occipital-ventral view) showing the anatomical measurements. Ac-Height of the foramen magnum. Ad-Width of the foramen magnum.

### Lateral surface measurements

M-Total skull length (TSL)/Laterally. The distance from the middle point of the lateral edge of the incisive bone to the middle point of the caudal lateral edge of the temporal bone (44). N-Length of the neurocranium (LNC) /Laterally. The distance from the middle point of the rostral edge of the orbit to the middle point of the caudal lateral edge of the temporal bone (45). O-Width of the neurocranium (WNC)/ Laterally: The distance from the top of the caudal dorsal margin of the orbit to the zygomatic process of the zygomatic bone (45). P-Orbital length (OL): The mediastinal vertical distance between the supraorbital and infraorbital margins of the orbit (41). Q-Orbital width (OW): The mediastinal horizontal distance between the rostral and caudal margins of the orbital rim (41). R-Orbital index. Orbital index = orbital width / orbital length \* 100 (41). S-Length of the temporal bone (LTB). The distance from the midpoint of the caudo-lateral border of the temporal bone to the extreme midpoint of the temporal bone within the orbit. T-Width of the temporal bone (WTB). The distance from the middle point of the dorsal edge of the temporal bone to the middle point of the ventral edge of the temporal bone. U-Skull index/laterally. Skull index=widest neurocranial width (laterally)/total skull length (laterally)\*100 (26-27).

### Ventral surface measurements

V-Total skull length (TSL)/Ventrally. The distance from the middle point of the rostral edge of the incisive bone ventrally to the middle point between the two occipital condyles (45). W-Length of skull base (LSB). The distance between the middle point of the ventral edge of the foramen magnum to the middle point of the rostral edge of the sphenoid bone ventrally (26-27). X-Width of skull base (WSB). The distance between the middle point of the zygomatic arches ventrally (44). Y-Distance between the two jugular processes (D2JP). The distance between the two terminal edges of the jugular processes (26-27). Z-Length of basal part of occipital bone (LBPOB). The distance between the middle point of the ventral edge of the foramen magnum to the middle point of the caudal edge of the sphenoid bone ventrally (26-27). Aa-Length of sphenoid bone (LSB). The distance between the middle point of the caudal edge of the sphenoid bone to the middle point of the rostral edge of the sphenoid bone ventrally (26-27). Ab-Skull index%/Ventrally. Skull index= Width of skull base (WSB)/ Total skull length (TSL)/Ventrally \* 100 (26-27). Ac-Height of the foramen magnum (HFM): The distance between the

midpoint of the dorsal and ventral edges of the foramen magnum (44). Ad-Width of the foramen magnum (WFM): The maximum distance between the occipital condyles (44). Ae-Foramen magnum index. Foramen magnum index = Height of the foramen magnum (HFM)/ Width of the foramen magnum (WFM)\* 100 (44). Af-Capacity of cranial cavity/cm<sup>3</sup>: All foramina of the cranial cavity were plugged with cotton, then the cavity was filled with mustard seeds through the foramen magnum. Then, the mustard seeds were emptied into a measuring cylinder to obtain the capacity of the cranial cavity (25,46,47).

## **Results**

The skull measurements of local sheep were evaluated during weeks 7 to 19 of pregnancy, including the dorsal, lateral, and ventral measurements of the skull (Tables 1-6).

### **Dorsal surface measurements**

The results demonstrated that the total length and width of the skull, as measured dorsally, increased progressively with age during weeks 7 to 19 of pregnancy, and these increases were minimal during the early weeks when the skull was relatively short. It was also noted that there were statistically significant differences ( $P \leq 0.05$ ) in the total length and width of the skull between fetuses aged 7-15 weeks of pregnancy. For the distance between the orbital foramina, significant differences ( $P \leq 0.05$ ) were found between fetuses aged 7-12 weeks and those aged 13-19 weeks of pregnancy. Likewise, with the variable of the length of the neurocranium dorsally, the significant differences ( $P \leq 0.05$ ) were concentrated between the age groups of 10-19 weeks of pregnancy, while the rest of the ages did not show significant differences ( $P \geq 0.05$ ). In terms of the widest width of the dorsal neurocranium, significant differences ( $P \leq 0.05$ ) were concentrated between the age groups of 7-13 weeks and 14-19 weeks. These findings reflect the rapid growth of the dorsal skull bones during later stages of gestation. By the advanced stages, the skull appeared relatively elongated, and the neurocranium took on an almost circular shape.

Statistical analysis of the correlation between age (in weeks), total length, total weight, head weight, and skull weight (excluding the mandibles) with various skull measurements revealed correlations ranging from medium to very strong positive correlation. A very strong positive correlation was observed between age in weeks and the variables of total skull length, total skull width, the distance between the two supraorbital foramina and dorsal neurocranium length, as well as with the variable of total length, total weight, and head weight with the above variables. The skull weight without mandibles showed a strong positive correlation with the variable of total skull length, neurocranium length, and dorsal neurocranium width and a medium positive correlation with total skull width and

distance between the two supraorbital foramina. All correlations were represented in the correlation coefficient plot, which ranged between 0.988-0.549 at a significant value less than ( $P < 0.05$ ).

Measurements conducted in this study revealed an increase in the growth of the length and width of the frontal bone with age during weeks 7-19 of pregnancy. A slight increase was observed in the first weeks of pregnancy (7-12 weeks), and the highest percentage of growth increase was in the period 12-13 weeks of pregnancy, while the highest percent of increase in the width of the frontal bone was in the period 12-14 weeks of pregnancy, until it reaches the maximum length and width of the frontal bone at the period 19-18 weeks of pregnancy, where this age period showed significant differences ( $P \leq 0.05$ ) with all the age periods. As for the length of the parietal bone, a slight growth was observed during weeks 7-9 of pregnancy, followed by a noticeable increase during weeks 9-10 of pregnancy, then it slowed down and increased in the period 12-13 weeks and 15-16 weeks of pregnancy, then the increase returned slightly until the parietal bone reached its maximum length in the period 18-19 weeks of pregnancy. As for the increase in the width of the parietal bone, it was slight in all age periods except for the period 9-10 weeks and 11-12 weeks of pregnancy, where a rapid increase in growth was observed with significant differences ( $P \leq 0.05$ ). As for the length and width of the squamous part of the occipital bone, an increase in growth in length and width was observed with age, and the highest increase was in the period 10-13 weeks of pregnancy until it reached the highest level of growth in the period 18-19 weeks of pregnancy, where this age period showed significant differences ( $P \leq 0.05$ ) with all the age periods. These findings highlight the rapid growth of the dorsal cranial bones during advanced stages of pregnancy and the development of curvature (arching) in these bones.

The results of the statistical analysis showed that the width of the foramen magnum increases significantly ( $P \leq 0.05$ ) with age, from  $2.52 \pm 0.29$  mm in the period 7-8 weeks of pregnancy and reaching  $11.29 \pm 1.54$  mm in the period 12-13 weeks of pregnancy until it reaches  $14.65 \pm 0.49$  mm in the period 18-19 weeks of pregnancy. As for the height of the foramen magnum, an acceleration in growth was observed in the period 7-8 weeks and to the period 12-13 weeks of pregnancy, reaching  $12.85 \pm 0.49$  mm by weeks 18-19 of pregnancy, with significant differences ( $P \leq 0.05$ ) for the last age period with all the age groups. As for the foramen magnum index exhibited a downward trend during weeks 7-11, then an upward trend from the period 12-16 weeks, then a downward trend again from the period 17-19 weeks, where the foramen magnum appeared almost oval.

There was a significant difference ( $P \leq 0.05$ ) in the dorsal skull index among different age groups, showing a decreasing trend with age from  $3.49 \pm 37.01$  at 12-13 weeks of gestation to  $0.35 \pm 35.70$  at 17-18 weeks of gestation.

Table 1a: Statistical differences between the age groups studied during (7-19) weeks of pregnancy and the measurements (Mean ± SEM) of dorsal variables in the skull of local sheep fetuses

Age groups (weeks)	Total skull length (TSL)/Dorsally/mm	Total skull width (TSW)/Dorsally/mm	Distance between the two supraorbital foramina (DSOF)/mm	Length of the neurocranium (LNC)/Dorsally/mm	Width of the neurocranium (WNC)/Dorsally/mm	Length of the frontal bone (LFB)/mm	Width of the frontal bone (WFB)/mm
7-8	37.71 ± 1.54 a	9.60 ± 1.23 ab	7.86 ± 0.13a	30.19 ± 1.09a	12.06 ± 1.09a	15.92 ± 1.01 a	12.59 ± 1.09a
8.1-9	50.87 ± 3.52 a	14.14 ± 0.97 b	10.02 ± 0.96ab	36.26 ± 2.95a	15.30 ± 1.17b	19.03 ± 1.97a	15.25 ± 1.70a
9.1-10	76.51 ± 3.76 b	17.43 ± 2.52 b	12.59 ± 1.37bc	47.24 ± 9.01ab	21.93 ± 2.32b	27.13 ± 0.24b	24.44 ± 1.78a
10.1-11	64.58 ± 3.97 bc	19.11 ± 2.05 b	14.45 ± 1.91cd	31.42 ± 16.13 cd	22.95 ± 3.44c	26.65 ± 1.22b	15.06 ± 1.65ab
11.1-12	79.13 ± 8.17c	20.32 ± 6.52 c	16.99 ± 0.65d	57.35 ± 14.22d	30.35 ± 3.04c	32.48 ± 1.16c	19.23 ± 0.61b
12.1-13	82.21 ± 10.68c	29.68 ± 0.77 cd	20.51 ± 0.86e	55.69 ± 17.67d	32.91 ± 4.01c	34.21 ± 2.14cd	24.19 ± 3.21bc
13.1-14	106.05 ± 3.59cd	34.57 ± 1.33 cd	20.98 ± 2.32e	75.89 ± 1.01e	33.63 ± 4.73d	37.35 ± 1.20d	28.57 ± 5.73bc
14.1-15	112.61 ± 3.59d	36.12 ± 0.64 de	25.04 ± 0.67fg	84.29 ± 4.94ef	42.90 ± 4.56d	44.15 ± 0.51e	24.71 ± 0.65bc
15.1-16	119.72 ± 1.48de	39.82 ± 0.68 e	25.91 ± 0.31fg	86.95 ± 1.24ef	45.39 ± 1.44e	44.13 ± 0.13e	26.18 ± 0.20c
16.1-17	129.17 ± 1.17de	44.22 ± 0.58 de	27.85 ± 0.20fgh	93.01 ± 2.48f	51.38 ± 1.81e	45.44 ± 0.38e	27.73 ± 0.20c
17.1-18	132.70 ± 0.17de	47.37 ± 0.60 e	28.92 ± 0.32gh	97 ± 0.75f	54.83 ± 0.75f	47.21 ± 0.29ef	29.41 ± 0.35c
18.1-19	134.70 ± 0.30 e	50.35 ± 1.05 e	30.10 ± 0.80h	99.25 ± 0.75f	57.25 ± 0.65f	48.85 ± 0.25f	31.10 ± 0.40c

Table 1b: Statistical differences between the age groups studied during (7-19) weeks of pregnancy and the measurements (Mean ± SEM) of dorsal variables in the skull of local sheep fetuses

Age groups (weeks)	Length of parietal bone (LPB)/mm	Width of parietal bone (WPB)/mm	Length of squamous part of occipital bone (LSPOB)/mm	Width of squamous part of occipital bone (WSPOB)/mm	Width of the foramen magnum (WFM)/mm	Height of the foramen magnum (HFM)/mm	Foramen magnum index %	Skull index/Dorsally%
7-8	11.82 ± 0.84a	10.89 ± 0.56a	8.25 ± 0.41a	1.67 ± 0.63a	2.52 ± 0.29a	3.53 ± 0.29a	139.65 ± 0.29a	25.45 ± 3.16a
8.1-9	14.49 ± 0.86a	13.59 ± 0.75b	11.30 ± 0.99a	4.82 ± 1.27ab	3.9 ± 0.57a	4.97 ± 0.57a	127.85 ± 0.57a	27.83 ± 0.85ab
9.1-10	24.03 ± 3.76ab	20.99 ± 1.69b	15.26 ± 0.53ab	6.79 ± 0.39bc	6.28 ± 1.40ab	7.37 ± 1.40ab	120.08 ± 1.40ab	22.73 ± 2.87abc
10.1-11	12.67 ± 0.83abc	13.52 ± 0.94c	5.80 ± 2.23ab	10.35 ± 1.20cd	5.03 ± 1.30bc	3.73 ± 1.30bc	69.25 ± 1.30bc	29.46 ± 1.43abcd
11.1-12	16.06 ± 0.61bcd	15.88 ± 1.38c	10.78 ± 1.91bc	13.86 ± 2.73de	9.46 ± 2.20bcd	7.93 ± 2.20bcd	84.21 ± 2.20bcd	24.35 ± 6.50abcde
12.1-13	18.84 ± 1.07bcd	18.55 ± 0.43cd	16.00 ± 1.56bc	16.38 ± 3.22ef	11.29 ± 1.54bcde	11.11 ± 1.54bcde	98.09 ± 1.54bcde	37.01 ± 3.49bcde
13.1-14	18.68 ± 0.90cd	19.26 ± 0.49cde	20.38 ± 0.19cd	19.92 ± 0.86fg	9.02 ± 0.135cde	8.07 ± 0.135cde	89.50 ± 0.135cde	32.64 ± 0.37cde
14.1-15	19.30 ± 2.66de	21.34 ± 0.59cde	17.44 ± 0.79cd	20.89 ± 3.88g	8.07 ± 1.01cde	8.59 ± 1.01cde	107.93 ± 1.01cde	32.06 ± 0.31cde
15.1-16	21.19 ± 0.50ef	22.03 ± 0.22def	22.82 ± 0.40d	23.49 ± 0.99g	8.60 ± 0.26cdef	8.58 ± 0.26cdef	100.04 ± 0.26cdef	33.24 ± 0.13de
16.1-17	24.49 ± 0.46ef	23.71 ± 0.33ef	28.95 ± 0.34e	28.19 ± 0.66h	11.21 ± 0.16def	10.21 ± 0.16def	91.65 ± 0.16def	34.23 ± 0.21de
17.1-18	25.98 ± 0.24f	24.86 ± 0.29fg	31.36 ± 0.46e	29.75 ± 0.36h	13.17 ± 0.36ef	11.41 ± 0.36ef	86.54 ± 0.36ef	35.70 ± 0.35e
18.1-19	27.05 ± 0.31f	25.80 ± 0.46g	33.25 ± 0.79e	31.10 ± 0.37h	14.65 ± 0.49f	12.85 ± 0.49f	87.85 ± 0.49f	37.37 ± 0.40e

Different letters within the same parameter indicate statistical differences between age groups at a significant value  $P \leq 0.05$ .

Table 2: Relationships between variables (age, total length, total weight, head weight, and skull weight without jaw) with the measurements of dorsal variables in the skull of local sheep fetuses during weeks (7-19) of pregnancy

Measurements of dorsal variables	Age	Total length	Total weight	Head weight	Skull weight
	(week)	(cm)	(g)	(g)	without jaw (g)
	R (P value)	R (P value)	R (P value)	R (P value)	R (P value)
Total skull length (TSL)/ Dorsally/ mm	0.968 (<0.001)	0.960 (<0.001)	0.882 (<0.001)	0.925 (<0.001)	0.631 (<0.001)
Total skull width (TSW)/ Dorsally /mm	0.966 (<0.001)	0.970 (<0.001)	0.914 (<0.001)	0.945 (<0.001)	0.549 (<0.001)
Distance between the two supraorbital foramina (DSOF)/mm	0.981 (<0.001)	0.976 (<0.001)	0.893 (<0.001)	0.930 (<0.001)	0.564 (<0.001)
Length of the neurocranium (LNC)/ Dorsally/mm	0.945 (<0.001)	0.932 (<0.001)	0.875 (<0.001)	0.912 (<0.001)	0.640 (<0.001)
Width of the neurocranium (WNC)/ Dorsally/mm	0.984 (<0.001)	0.988 (<0.001)	0.939 (<0.001)	0.965 (<0.001)	0.606 (<0.001)
Length of the frontal bone (LFB)/mm	0.912 (<0.001)	0.939 (<0.001)	0.939 (<0.001)	0.916 (<0.001)	0.612 (<0.001)
Width of the frontal bone (WFB)/mm	0.687 (<0.001)	0.696 (<0.001)	0.675 (<0.001)	0.658 (<0.001)	0.583 (<0.001)
Length of parietal bone (LPB)/mm	0.674 (<0.001)	0.680 (<0.001)	0.685 (<0.001)	0.671 (<0.001)	0.701 (<0.001)
Width of parietal bone (WPB)/mm	0.783 (<0.001)	0.789 (<0.001)	0.798 (<0.001)	0.753 (<0.001)	0.738 (<0.001)
Length of squamous part of occipital bone (LSPOB)/mm	0.719 (<0.001)	0.734 (<0.001)	0.725 (<0.001)	0.708 (<0.001)	0.703 (<0.001)
Width of squamous part of occipital bone (WSPOB)/mm	0.906 (<0.001)	0.920 (<0.001)	0.923 (<0.001)	0.906 (<0.001)	0.598 (<0.001)
Width of the foramen magnum (WFM)/mm	0.766 (<0.001)	0.764 (<0.001)	0.721 (<0.001)	0.721 (<0.001)	0.417 (0.014)
Height of the foramen magnum (WFM)/mm	-0.456 (0.005)	-0.450 (0.005)	-0.350 (0.371) <sup>N</sup>	-0.381 (0.381) <sup>N</sup>	0.220 (0.889) <sup>N</sup>
Foramen magnum index %	0.575 (<0.001)	0.577 (<0.001)	0.590 (<0.001)	- 0.613 (<0.001)	-0.161 (<0.001)
Skull index/ Dorsally%	0.829 (<0.001)	0.830 (<0.001)	0.828 (<0.001)	0.815 (<0.001)	0.451 (<0.001)

R: Correlation coefficient, N: No significant difference.

The results of the statistical analysis showed a very strong positive correlation between the length of the frontal bone and the width of the squamous part of the occipital bone with the variable age in weeks, and a very strong positive correlation also for both variables with the other variables which are total length, total weight, and head weight. At the same time, there was a strong positive correlation between the width of the frontal bone and the length and width of the parietal bone, and the length of the squamous part of the occipital bone with the variable age in weeks. There is also a strong positive correlation between these variables with the variables total length, total weight, head weight, and skull weight without the mandibles, except for the variables width of the frontal bone and width of the squamous part of the occipital bone, the correlation of both with the variable weight of the skull without mandibles was moderately positive. There was a strong positive correlation between the

foramen magnum width variable and age in weeks, also there was a strong positive correlation between this variable and other variables (total length, total weight, head weight) and the correlation was moderately positive with the skull weight variable without the mandibles, while the foramen magnum height variable had a moderately positive correlation with the age variable in weeks and total length and a weakly positive correlation with the other variables (total weight, head weight) and a weakly positive correlation with the variable skull weight without mandibles. There was also a moderately positive correlation for the foramen magnum index with the variables age, total length, and total weight a strong positive correlation with the head weight, and a weakly positive correlation with the skull weight without mandibles. As for the dorsal skull index, there was a strong positive correlation with the variables age, total length, total weight, and head weight, and a moderately positive

Table 3: Statistical differences between the age groups studied during weeks (7-19) of pregnancy and the measurements (Mean ± SEM) of lateral variables in the skull of local sheep fetuses.

Age groups (weeks)	Total skull length (TSL)/Laterally/mm	Length of the neurocranium (LNC)/Laterally/mm	Width of the neurocranium (WNC)/Laterally/mm	Orbital length (OL)/mm	Orbital width (OW)/mm	Orbital index %	Length of the temporal bone (LTB)/mm	Width of the temporal bone (WTB)/mm	Skull index %/laterally
7-8	20.19±0.82a	11.46±0.30a	8.38±0.21a	5.70±0.12a	5.98±0.34a	105.04±6.95a	1.65±0.42a	1.65±0.18a	41.59±0.61a
8.1-9	25.54±1.24ab	14.90±1.05a	11.07±0.74a	7.31±0.29b	8.92±0.29b	122.43±7.18ab	3.65±0.72a	2.75±0.67a	43.32±1.58ab
9.1-10	37.61±1.92b	21.39±1.19b	14.41±1.21b	10.19±0.30c	11.43±0.61c	112.70±9.20ab	6.51±0.82ab	6.59±0.61b	38.20±1.64abc
10.1-11	59.34±14.20c	26.19±1.81b	22.46±1.87c	11.31±0.46c	13.27±0.65d	85.34±2.57ab	16.40±6.80bc	5.17±1.11bc	43.04±11.84abcd
11.1-12	54.24±1.88cd	32.46±1.12c	29.54±0.98d	13.12±0.33d	16.30±0.47e	80.56±1.43ab	10.82±0.78cd	7.09±0.80bc	54.56±1.38bcde
12.1-13	66.38±3.99cde	39.85±2.72d	32.66±1.10e	14.26±0.68d	18.57±0.82f	76.75±0.80ab	14.62±1.40cd	8.19±0.78cd	49.47±2.78abcde
13.1-14	76.01±4.69def	45.86±1.69de	38.44±0.27f	16.13±0.35e	19.23±0.06f	83.84±1.54ab	18.77±2.27cd	9.96±0.09de	51.22±3.51bcde
14.1-15	73.14±3.57def	44.82±4.01de	38.96±1.56f	16.60±0.62e	19.69±0.49f	84.54±5.10ab	16.88±2.02cd	10.44±1.09e	53.73±4.82bcde
15.1-16	74.00±0.08ef	41.23±0.85def	40.13±0.45f	16.31±0.20e	19.66±0.13f	83.13±1.60bc	17.34±0.17cd	11.74±0.39e	54.25±0.67bcde
16.1-17	77.32±2.17ef	41.17±2.43ef	43.75±0.77g	17.30±1.15e	21.11±0.45g	81.72±3.70cd	17.55±0.63d	14.09±0.20f	56.63±0.59cde
17.1-18	82.19±0.20f	46.56±0.28ef	46.31±0.38gh	20.31±0.24f	22.35±0.22gh	90.83±0.54de	18.75±0.19d	14.87±0.17f	56.33±0.36de
18.1-19	20.19±0.05f	48.25±0.20f	48.15±0.43h	21.80±0.17g	23.10±0.34h	94.40±0.66e	18.75±0.37d	15.55±0.23f	57.52±0.55e

Different letters within the same parameter indicate statistical differences between age groups at a significant value  $P \leq 0.05$ .

Table 4: Statistical differences between the age groups studied during weeks (7-19) of pregnancy and the measurements (Mean ± SEM) of ventral variables in the skull of local sheep fetuses

Age groups (weeks)	Total skull length (TSL)/Ventrally/mm	Length of skull base (LSB)/mm	Width of skull base (WSB)/mm	Distance between the two jugular processes (D2JP)/mm	Length of basal part of occipital bone (LBPOB)/mm	Length of sphenoid bone (LSB)/mm	Skull index %/Ventrally	Volume (capacity) of cranial cavity/cm <sup>3</sup>
7-8	15.88±0.33a	4.99±1.56a	10.62±0.49a	6.25±0.69a	2.71±0.19a	1.74±0.51a	66.85±2.38a	6.16±0.16a
8.1-9	21.26±0.85a	7.46±0.62a	13.42±1.19ab	6.47±0.44a	3.78±0.44ab	2.78±0.01a	63.64±7.43a	6.00±0.28a
9.1-10	31.24±2.67b	13.74±0.49ab	17.18±0.79bc	13.11±0.44b	5.17±0.66bc	4.90±1.26ab	55.79±3.48ab	6.00±0.01a
10.1-11	38.02±2.61b	24.03±10.27b	16.07±1.91bc	10.22±2.46bc	5.82±0.65cd	3.27±0.51bc	42.18±4.13ab	5.83±0.60a
11.1-12	47.65±3.70c	18.52±1.10b	20.22±0.65c	16.05±1.97cd	7.09±0.97de	5.33±0.13c	42.93±5.13ab	8.33±0.88a
12.1-13	57.06±5.88d	19.91±3.18b	25.32±3.82d	17.91±0.50cd	7.67±0.79e	5.11±1.23c	44.05±1.17ab	12.83±0.83b
13.1-14	61.03±1.84de	18.04±0.71b	31.63±2.34de	16.53±1.59de	10.38±0.68f	7.73±0.25d	52.17±2.56ab	16.50±1.44c
14.1-15	64.93±0.37ef	22.01±1.97b	26.25±1.13def	21.06±0.47ef	11.06±0.28fg	7.79±0.31d	40.55±0.13ab	22.66±2.18d
15.1-16	69.16±0.66fg	23.17±0.16b	27.82±0.05def	21.24±0.63ef	12.19±0.09fg	9.57±0.26e	40.25±0.15bc	26.00±0.70e
16.1-17	72.15±0.35fg	22.17±0.10b	28.75±0.37ef	24.70±0.27fg	13.21±0.34gh	11.43±0.32f	39.85±0.13cd	31.00±0.57f
17.1-18	74.41±0.40g	22.60±0.23b	30.38±0.22f	26.36±0.46g	14.19±0.27g	12.67±0.27fg	40.82±0.69de	32.87±0.32fg
18.1-19	76.10±0.59g	23.55±0.31b	31.80±0.11f	27.30±0.36g	14.90±0.45g	13.75±0.37g	41.79±5.15e	34.25±0.43g

Different letters within the same parameter indicate statistical differences between age groups at a significant value  $P \leq 0.05$ .

correlation with the skull weight without mandibles. All relationships were represented within the correlation coefficient chart, which ranged between 0.939 and 0.161-, with a significance level of  $P < 0.001$

#### Lateral surface measurements

The measurements study of the skull of local sheep fetuses showed that the total lateral skull length increased with age, it was  $20.19 \pm 0.82$  in the age period 7-8 weeks of pregnancy to reach  $82.19 \pm 0.20$  in the period 17-18 weeks of pregnancy, as well as for the length and width of the neurocranium laterally within the same age period, where this age period showed significant differences ( $P \leq 0.05$ ) with all the age. This illustrates the rapid growth of the lateral parts in advanced age stages with the presence of curvature (arching) in the zygomatic arch.

The length of the orbit increased significantly ( $P \leq 0.05$ ) with age, where the increase in length was faster in the age period from 7-8 weeks to 11-12 weeks of pregnancy, then became slower after week 12. The width of the orbit did not differ from its length, as it also increased with age, but the

increase was faster in the period from 7-8 weeks to 12-13 weeks of pregnancy. As noted, there was a significant difference ( $P \leq 0.05$ ) in the orbital index between the mentioned age periods, noting that it decreased with age, as this age period showed significant differences ( $P \leq 0.05$ ) with all the as mentioned earlier age periods. The orbit appeared almost oval.

The length of the temporal bone increased with age, where it was observed that the increase was rapid in the age periods 7-8 weeks to 10-11 weeks of pregnancy, then a slowdown in growth was observed until it reached the maximum increase in length in the period 18-19 weeks of pregnancy, while the width of the temporal bone was observed to grow more with age. As for the lateral skull index, it showed an ascending and descending symmetry in the period 8-14 weeks of pregnancy, then achieved an ascending growth with age, where this age period showed significant differences ( $P \leq 0.05$ ) with all mentioned earlier age periods. This illustrates the rapid growth of the lateral parts in advanced age stages.

Table 5: Relationships between variables (age, total length, total weight, head weight, and skull weight without jaw) with the measurements of lateral variables in the skull of local sheep fetuses during weeks (7-19) of pregnancy

Measurements of dorsal variables	Age	Total length	Total weight	Head weight	Skull weight
	(week)	(cm)	(g)	(g)	without jaw (g)
	R (P value)	R (P value)	R (P value)	R (P value)	R (P value)
Total skull length (TSL)/Laterally/mm	0.889 ( $<0.001$ )	0.891 ( $<0.001$ )	0.744 ( $<0.001$ )	0.798 ( $<0.001$ )	0.356 (0.11) <sup>N</sup>
Length of the neurocranium (LNC)/Laterally/mm	0.901 ( $<0.001$ )	0.903 ( $<0.001$ )	0.739 ( $<0.001$ )	0.797 ( $<0.001$ )	0.378 (0.033)
Width of the neurocranium (WNC)/Laterally/mm	0.970 ( $<0.001$ )	0.973 ( $<0.001$ )	0.857 ( $<0.001$ )	0.974 ( $<0.001$ )	0.441 (0.023)
Orbital length (OL)/mm	0.970 ( $<0.001$ )	0.971 ( $<0.001$ )	0.887 ( $<0.001$ )	0.918 ( $<0.001$ )	0.504 ( $<0.001$ )
Orbital width (OW)/mm	0.952 ( $<0.001$ )	0.955 ( $<0.001$ )	0.822 ( $<0.001$ )	0.870 ( $<0.001$ )	0.456 ( $<0.005$ )
Orbital index%	-0.186 (0.119) <sup>N</sup>	-0.166 (0.156) <sup>N</sup>	-0.171 (0.141) <sup>N</sup>	-0.202 (0.084) <sup>N</sup>	0.178 (0.081) <sup>N</sup>
Length of the temporal bone (LTB)/mm	0.764 ( $<0.001$ )	0.763 ( $<0.001$ )	0.610 ( $<0.001$ )	0.665 ( $<0.001$ )	0.230 (0.177) <sup>N</sup>
Width of the temporal bone (WTB)/mm	0.967 ( $<0.001$ )	0.972 ( $<0.001$ )	0.920 ( $<0.001$ )	0.949 ( $<0.001$ )	0.613 ( $<0.001$ )
Skull index %/laterally	0.724 ( $<0.001$ )	0.724 ( $<0.001$ )	0.718 ( $<0.001$ )	0.739 ( $<0.001$ )	0.393 ( $<0.001$ )

R: Correlation coefficient, N: No significant difference.

There was a very strong positive correlation between the measurements total skull length laterally and length and width of the neurocranium laterally with the variables age and total length, while the correlation between total skull length laterally and neurocranium length laterally was strongly positive with the variables total weight and head

weight, and weak with the variable weight of the skull without the mandibles. As for the width of the neurocranium laterally, the correlation was strongly positive with the variables total weight and head weight and moderate with the weight of the skull without the mandibles. The results of the statistical analysis showed a very strong positive correlation

between the length and width of the orbits with age in weeks, also a strong positive correlation between it and the other variables total length, total weight, and head weight, and moderately positive with the variable of weight of the skull without the mandibles. As for the orbital index, the correlation was weakly positive with the variables age, total length, total weight, and head weight, and weakly positive with the variable of weight of the skull without the mandibles. A very strong positive correlation was observed

between the length and width of the temporal bone and the other variables (age, total length, total weight and head weight) and weakly positive with the variable of weight of the skull without the mandibles. The correlation between the lateral skull index and the variables age, total height, total weight and head weight was strong, and weak with the weight of the skull without the mandibles. All correlations were within the correlation coefficient plot, which ranged from 0.974-0.166 at a significant value less than ( $P < 0.001$ ).

Table 6: Relationships between variables (age, total length, total weight, head weight, and skull weight without jaw) with the measurements of ventral variables in the skull of local sheep fetuses during weeks (7-19) of pregnancy

Measurements of dorsal variables	Age	Total length	Total weight	Head weight	Skull weight
	(week)	(cm)	(g)	(g)	without jaw (g)
	R (P value)	R (P value)	R (P value)	R (P value)	R (P value)
Total skull length (TSL)/Ventrally/mm	0.959 (<0.001)	0.962 (<0.001)	0.836 (<0.001)	0.887 (<0.001)	0.482 (0.003)
Length of skull base (LSB)/mm	0.639 (<0.001)	0.620 (<0.001)	0.480 (0.003)	0.520 (<0.001)	0.190 (0.266) <sup>N</sup>
Width of skull base (WSB)/mm	0.889 (<0.001)	0.889 (<0.001)	0.767 (<0.001)	0.820 (<0.001)	0.449 (0.006)
Distance between the two jugular processes (D2JP)/mm	0.949 (<0.001)	0.954 (<0.001)	0.895 (<0.001)	0.921 (<0.001)	0.6 (<0.001)
Length of basal part of occipital bone (LBPOB)/mm	0.977 (<0.001)	0.978 (<0.001)	0.915 (<0.001)	0.950 (<0.001)	0.592 (<0.001)
Length of sphenoid bone (LSB)/mm	0.952 (<0.001)	0.959 (<0.001)	0.954 (<0.001)	0.969 (<0.001)	0.715 (<0.001)
Skull index%/Ventrally	- 0.691 (<0.001)	- 0.692 (<0.001)	-0.538 (<0.001)	-0.580 (<0.001)	-0.270 (0.111) <sup>N</sup>
Volume (capacity) of cranial cavity/cm <sup>3</sup>	0.956 (<0.001)	0.959 (<0.001)	0.966 (<0.001)	0.982 (<0.001)	0.874 (<0.001)

R: Correlation coefficient, N: No significant difference.

### Ventral surface measurements

A measurements study of the skull of local sheep fetuses showed that the total skull length ventrally increased with age, starting from 7-8 weeks to 13-14 weeks of pregnancy. The skull base length also increased with age, and an acceleration in growth was observed from 7-8 weeks to 12-13 weeks of pregnancy. The width of the skull base also increased with age. The distance between the two jugular processes increased with age, where an acceleration in growth was observed from the period 7-8 weeks to 9-10 weeks of pregnancy, then slight increases occurred from the period 13-14 weeks to 18-19 weeks of pregnancy, where this age period showed significant differences ( $P \leq 0.05$ ) with all mentioned earlier age periods. This illustrates the accelerated growth of the ventral parts during the later stages of pregnancy.

The length of the basal part of the occipital bone also increased with age, and growth acceleration was observed in the period 7-8 weeks to 12-13 weeks of pregnancy, then slight increases occurred in the period 13-14 weeks to 18-19 weeks of pregnancy, where this age period showed

significant differences ( $P \leq 0.05$ ) with all mentioned earlier age periods. The length of the sphenoid bone increased with age, and growth accelerated in the period 7-8 weeks to 16-17 weeks of pregnancy, then the increases became slight in the period 16-17 weeks to 18-19 weeks of pregnancy, where this age period showed significant differences ( $P \leq 0.05$ ) with all mentioned earlier age periods. This illustrates the rapid growth of the bones of the skull base in advanced age stages.

The ventral skull index differed significantly ( $P \leq 0.05$ ) among the mentioned age groups, noting that it decreased with age. It was noted that the size of the cranial cavity increased with age, where the increases were slight in the period 7-8 weeks to 10-11 weeks of pregnancy, then decreased in the period 10-11 weeks to 11-12 weeks of pregnancy, then accelerated in the period 12-13 weeks until reaching its maximum in the period 18-19 weeks of pregnancy, where this age period showed significant differences ( $P \leq 0.05$ ) with all mentioned earlier age periods. This illustrates the rapid growth of the cranial cavity in the advanced stages of age.

The statistical analysis results showed a very strong positive correlation between the total skull length ventrally and the variables total length, total weight, and head weight, and a weak positive relationship with the variable of skull weight without the mandibles. As for the length of the skull base, the correlation was strongly positive with the variable age and total length, moderately positive with the variables total weight and head weight, and weakly positive with the variable of skull weight without the mandibles. As for the width of the skull base, there was a very strong positive correlation with the variables age, total length, total weight, and head weight, and moderately positive with the variable of skull weight without the mandibles. As for the distance between the two jugular processes, the length of the basal part of the occipital bone and the length of the sphenoid bone, the statistical analysis results showed a very strong positive correlation between total ventral skull length and the variables of total length, total weight, and head weight, with a weak positive correlation to skull weight without mandibles, while the correlation was moderately positive for the length of the sphenoid bone with the variable of skull weight without the mandibles. The ventral skull index had a strong positive correlation with the variables age and total height, a medium positive correlation with the variables total weight and head weight, and a weak positive correlation with the variable of skull weight without the mandibles. As for the capacity of the cranial cavity, all relationships fell within the correlation coefficient plot, ranging from 0.982 to 0.270, with a significance level of ( $P < 0.001$ ).

## **Discussion**

### **Dorsal surface measurements**

During the 7<sup>th</sup> to 19<sup>th</sup> weeks of pregnancy showed an increase in these measurements with the advancement of foetal age, which can be explained by the increase in foetal growth (50). Sivachelvan *et al.* (51) discovered in their study of foetal development in the skull of the Sahel goat that the developmental changes that occur before birth in the organs and tissues of the body, in general, are predetermined by postnatal requirements. The results of the current study can be explained by the fact that the higher the cranial values and measurements, the greater the growth of the skull and brain, and this growth continues chronologically with the advancement of foetal age across the three trimesters of pregnancy with the highest values in the third trimester of pregnancy. At this stage, the foetal brain is likely to acquire an adult form and be able to function after birth (52).

The findings presented by Özüdoğru *et al.* (53) regarding the cranial measurements of Konya Merino sheep revealed notable distinctions in various parameters, including skull length, skull width, the maximum dimensions of the nasal bone, medial frontal length, facial width, foramen magnum height, maximum foramen magnum width, maximum frontal bone width, and minimum interorbital width. These

observations align with the current study, which also identified significant differences in skull length and width among fetuses aged 7-15 weeks of gestation. Karimi *et al.* (11) identified a negative correlation between the cranial capacity of Iranian Mehraban sheep and skull length, contrasting with the findings of the present study, which revealed a very strong positive correlation between cranial cavity capacity and all variables.

A study conducted by Jashari *et al.* (54) reported that the dimensions of the foramen magnum in Sharri sheep are used in sex determination, as the foramen magnum in females was larger than that in males, the difference in the width of the foramen magnum only was significant. While a study conducted by Günay and Altinkök (55) showed that the area of the foramen magnum is larger in males compared to females and the difference was significant, while the results of the current study showed that the width of the foramen magnum increases significantly with age, from  $2.52 \pm 0.29$  mm in the period 7-8 weeks of pregnancy and reaches  $11.29 \pm 1.54$  mm in the period 12-13 weeks of pregnancy, until it reaches  $14.65 \pm 0.49$  mm in the period 18-19 weeks of pregnancy. As for the height of the foramen magnum, an acceleration in growth was observed in the period 7-8 weeks and to the period 12-13 weeks of pregnancy, until it reached  $12.85 \pm 0.49$  mm in the period 18-19 weeks of pregnancy, with significant differences for the last age period with all the age groups. As for the index of the foramen magnum, showed a downward trend from the period 7-11 weeks, then an upward trend from the period 12-16 weeks, then a downward trend again from the period 17-19 weeks, where the foramen magnum appeared almost oval. In a morphometric study conducted by Özkan *et al.* (44) on skulls of domesticated cattle (*Bos taurus L.*) and wild buffalo (*Bubalus bubalis L.*) in Türkiye, was observed that the increase in foramen height was inversely proportional to the foramen width, with significant differences for the last age group (7 years old) with all mentioned earlier age groups (3-7 years old) where the foramen magnum was more circular in cattle, while it was oval in buffalo, however, the significant difference was only between the foramen magnum height values, where height showed an effect on the shape of the foramen magnum in both species. The value of the foramen magnum index in the comparative morphological study conducted by Ekici *et al.* (56) between the skulls of Akkaraman sheep and Kangal Akkaraman sheep using a 3D model and computed tomography was determined as an average of  $106.92 \pm 10.11$  in Akkaraman sheep and  $107.76 \pm 14.71$  in Kangal Akkaraman sheep, which explains the oval shape of the foramen and is attributed to the fact that the width of the foramen magnum is greater than its height, the difference in the value between the two types of sheep mentioned earlier may be due to breed differences and differences in the measurement methods used, which is consistent with the results of the current study in local sheep.

A strong link was found between age in weeks and total skull length, total skull width, distance between the two supraorbital foramina, and dorsal neurocranium length. There was also a link between total length, total weight, and head weight and the above variables. The weight of the skull without the mandibles was strongly linked to the total length of the skull, the length of the neurocranium, and the width of the neurocranium dorsally. It was also somewhat linked to the total width of the skull and the distance between the two supraorbital foramina. The latter results are in line with the Konya Merino skull measurements (53) which showed a strong negative or positive correlation between the features. The strongest negative correlation was found between the largest neurocranial width, the largest brain width, and the supraorbital foramen distance.

#### **Lateral surface measurements**

Karimi *et al.* (11) found a very strong negative correlation between the orbital index and the skull length, while they found a very weak positive correlation between the orbital index and the skull width in Iranian Mehraban sheep, as for the results of the current study, found a weak direct correlation between the orbital index and the total length variable. The results of the two measurements (height and width of the orbit) showed that the orbital cavity took an almost circular shape, as the results showed a very strong positive correlation between the length and width of the orbit with age in weeks, and there was also a strong positive correlation between it and other variables total length, total weight, and head weight and a moderate positive correlation with the variable of skull weight without mandibles, indicating that skull weight without mandibles has a lesser effect on the dimensions of the orbits compared to other factors (age, total length, total weight and head weight). Compared to the measurements morphological study conducted by Özkan *et al.* (44) of skulls of domesticated cattle (*Bos taurus L.*) and wild buffalo (*Bubalus bubalis L.*) in Turkey, the width of the orbit showed almost similar lengths in the two species, as the main difference in orbital measurements was only in height, as the height of the orbit was greater than its width in cattle skulls, as a difference was observed in the same measurements obtained from buffalo skulls.

#### **Ventral surface measurements**

The results of the current study showed that the correlation was strongly positive for the length of the skull base with the variable (age and total length), which is consistent with Dalga *et al.* (13) in their measurements morphological study of the skull of adult Hemshin sheep, where they found a strong positive correlation between the total length and the length of the base, and with de La Barra *et al.* (57) who specify that the detected outer difference in the cranial area of Suffolk Down Sheep cannot be reasoned to the rest of the bony structures of the cranial area, whether

in length, width, or height, it was detected that the difference of the vertical measurement is similar to the difference of separate bones that contribute in a particular measurement as portion of a plasticity-modulating tool self-determining of the genetic difference of individually bone. The measurements of the skull are quite beneficial in defining the productive prospective of a sheep strain (58-62).

#### **Conclusion**

The present study finds that notable differences in skull length and width were identified among fetuses aged 7-15 weeks of gestation, with a robust positive association between cranial cavity capacity and all variables. The width of the foramen magnum markedly increases with age. The foramen magnum index exhibited a declining trend from weeks 7 to 11, followed by an ascending trend from weeks 12 to 16, and then a further decline from weeks 17 to 19, during which the foramen magnum appeared nearly oval in shape. A tenuous direct association exists between the orbital index and the overall length variable, whereas the orbital cavity assumed a nearly circular configuration. This study serves as a foundational record of osteomorphometric characteristics in Iraqi domestic sheep fetuses due to the scarcity of existing data on this subject. The cranial measures are essential for comprehending the production capacity of this sheep breed.

#### **Acknowledgements**

At the finale of the current work, both authors could not skip their appreciation to the staff in the Department of Anatomy, College of Veterinary Medicine, University of Mosul, Mosul, Iraq, as well as the staff in the slaughterhouses in Mosul city who helped us in this work with the obtainable and grounding of domestic sheep fetuses' skulls samples.

#### **Conflict of interest**

The authors state that there is no conflict of interest in the publication of this study.

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## دراسة تطور الجمجمة العصبية في الأغنام العراقية المحلية: دراسة شكلية قياسية للعظام

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### الخلاصة

الجمجمة عبارة عن مجموعة من العظام المتماثلة وغير المتماثلة التي تحمي الدماغ وتؤدي الأعضاء الحسية. يحدد شكل الجمجمة بنية الرأس، والتي ترتبط ارتباطاً وثيقاً بمختلف الخصائص الفيزيائية والشكلية المستخدمة عادةً لتصنيف السلالات المختلفة من الحيوانات، وملفاتها الوراثية، وارتباطها الوثيق بالبيئة الخارجية. يهدف هذا العمل إلى تحديد القياسات الشكلية للجمجمة العصبية وقاعدة الجمجمة وسعة التجويف القحفي باستخدام ثمانية واربعين جنيناً من الأغنام المحلية العراقية في عمر ٥٠-١٥٥ يوماً من الحمل، تم قياسها باستخدام مقياس الورنية الإلكترونية وشريط القياس. تم تحضير جماجم الأجنة عن طريق النقع باستخدام هيدروكسيد الصوديوم. تم الحصول على سعة التجويف القحفي عن طريق ملئه ببذور الخردل من خلال الثقب الكبير. تم أخذ اثنين وثلاثين قياساً شكلية للعظام ضمن الأسطح الظهرية والوحشية والبطنية. وقد أظهرت الدراسة فروقاً معنوية في طول وعرض الجمجمة عند ٧-١٥ أسبوعاً من الحمل، وكان الارتباط بين سعة التجويف القحفي قوياً جداً وإيجابياً مع جميع المتغيرات. بينما يزداد عرض الثقب الكبير بشكل ملحوظ مع تقدم الحمل. وأظهر مؤشر الثقب الكبير اتجاهات تنازلياً من الفترة ٧-١١ أسبوعاً، ثم اتجاهات تصاعدياً من الفترة ١٢-١٦ أسبوعاً، ثم اتجاهات تنازلياً مرة أخرى من الفترة ١٧-١٩ أسبوعاً، حيث ظهر بيضاً تقريباً. وكان الارتباط ضعيفاً بين مؤشر الحجاج ومتغير الطول الكلي، واتخذ تجويف الجمجمة شكلاً دائرياً تقريباً. يمكن استخدام قياسات الجمجمة في برامج التربية لتحسين السمات المرغوبة، وتحقيق أهداف الإنتاج المحددة، والمساعدة في تحديد الحيوانات ذات السمات الوراثية المتوقعة.