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Morphometric Development of the Vertebral Segments of the Vertebral Column in the Goat (*Capra hircus*) During the Fetal Period

Desarrollo Morfométrico de los Segmentos Vertebrales de la Columna Vertebral en Cabra (*Capra hircus*) Durante el Periodo Fetal

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SUMMARY: Understanding normal fetal growth rates of the vertebral column, and between species, provide a basis to establish reference values for evaluation of body development and estimation of fetal age by ultrasonography. Goats are also widely used in biomedical prenatal research and are still considered a key to understanding the skeletal development. This study was carried out to clarify growth of length of vertebral column at segmental, regional, and total level of vertebral column in the fetal goats during different gestational age. The length of each vertebral segment of 25 goat fetuses, aged between 6 and 20 weeks were measured for each vertebra using a digital caliper. Our study demonstrated differences among various fetal ages in terms of regional, segmental, and total growth rate of the length of vertebral segments. With increase of fetal age, the relative length of vertebral segments of cervical, thoracic and lumbar regions diminished, whereas sacral and caudal regions increased in relative length. The thoracic vertebrae were the longest followed by cervical, lumbar, caudal, and sacral regions except at the oldest fetuses where caudal region became longer than lumbar region. Although the longest and shortest vertebral segments in cervical and lumbar regions were consistent among age groups, the trend of segmental growth of the vertebral regions was variable. Based on these detailed findings, the relative regional lengths of vertebral column were essentially different among fetal goats, humans, and neonatal rats. There is also a general trend of increasing segmental and regional initial growth and there is a relatively significant increase in growth rate caudally along the column during fetal period. This research yield important results that may be also useful for future orthopedic studies that contemplate the use of goat as a new model for the human spine.

KEY WORDS: Segmental growth; Vertebrae; Morphometric; Goat fetus; Prenatal development.

INTRODUCTION

The median unpaired vertebral column of the domestic mammals consists of a fairly constant number of bones, extending from the head to the tail. Vertebral column houses and protects the spinal cord, allows for muscle attachment, and acts as a support structure (Nickel *et al*., 1986). The progress of the human spinal research depends on the development achieved in laboratory–and animal based scientific studies (Wang *et al*., 2015). In addition, due to limited availability of human cadaver spine, researchers are constantly seeking for representative animal models that reflect the anatomical and biomechanical characteristics of the human and spine sheep (Wilke *et al*., 1997; Mageed *et al*., 2013; Wang *et al*.) deer (Kumar *et al*., 2000) calves, pigs, and sheep (Kettler *et al*., 2007) large animals (Sheng *et al*., 2010). These studies which claimed morphometrical data on the characteristics anatomy of the animal spine are essential for designing and interpreting results from studies using this animal. They also found that the deer, sheep, and bovines are useful models for human spinal orthopedic research due to their similarity in morphometrical features of the thoracolumbar spine, with certain limitation for the cervical spine.

To comprehend completely the morphometrical variations of the vertebral column between the animals and humans, more attention should be paid on their ontogenesis.

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In this respect, literature pertaining to the morphometrical development of the various parts of the vertebral column in the fetal period of the domestic animals and humans, using direct measurements, is notably sparse. Recently, such experiments have been carried out by Nourinezhad *et al*. (2013), in the thoracic region of the vertebral column in the sheep during the fetal period, respectively. According to them, the segmental and total vertebral growth pattern in the fetal sheep are similar to those in the fetal humans.

On the other hand, understanding normal fetal growth rates of the vertebral column, and between species, provide a basis for the establishing of reference values for evaluation of the maturation, regional differences in growth that influence overall body form, and estimation of fetal age in ultrasonography. Kandiel *et al*. (2015) in the goat and Santiago-Moreno *et al*. (2005) in the sheep have measured, by ultrasonography, the length of thoracic and lumbar vertebrae to estimate fetal age and fetal growth. Accordingly, because of their size and development rate close to that of the human fetus, the small ruminants (sheep and goat) have been the model of choice for research on skeletal development (Morel *et al*., 2012), and because no information has been reported dealing with fetal development of the entire vertebral column in the goats , the present study was carried out to clarify the prenatal metric growth of the goat vertebral column at the regional, segmental, and total levels in the fetal period during different gestational ages using direct measurements, to compare with those of previous reports in the adult animals and humans.

MATERIAL AND METHOD

Twenty five goat fetuses were used in this study. The specimen without macroscopically visible lesions or other gross abnormalities were collected from a local abattoir. The fetuses were fixed by immersion in 10 % natural formalin. The estimated age of the fetuses was ascertained from crown-rump length (CRL) and the external appearance (Sivachelvan *et al*., 1996). The specimen with 10 to 37 cm body length were classified into 5 groups, including 6-8, 9-11, 12-14, 15-17, and 18-20 weeks (Sivachelvan *et al*., 1996) and 5 animals were included in each group.

A midline ventral skin incision was made from atlas to pelvic symphysis. Then, all the visceral structures, the attached muscles and surrounding tissues throughout the ventral surface of entire vertebral column were removed by a carful surgical dissection, leaving ligaments and intervertebral discs intact to maintain the physiological curvature of the spine.

The vertebral segments of entire vertebral column for each region were distinguished by the osteological features of the vertebral column in goat reported by Nickel *et al*. All rib-bearing vertebrae have been regarded as thoracic, and all vertebrae with elongated transverse process lying caudal to the rib-bearing vertebrae have been termed lumbar. The first sacral vertebra has been recognized by articulation of its transvers process with the wing of ilium. The first caudal vertebra has been designated by the interarcuate space between the sacrum and first caudal vertebra through bending the tail downwards. The positions of the boundaries for the various regions of the vertebral column were shown in Fig 1. After that, the number of vertebrae of the vertebral of column in the various regions was counted and then following variables were analyzed. Because the pattern of the vertebral length as a good indicator tended to be different from other vertebral dimensions, as reported by Kida *et al*. (1999), in the present study the length of the vertebral segments was measured as follows.

Fig 1. Ventral view of the fetal goat showing the boundaries of the various regions of the vertebral column (indicating by pins) and definition of the vertebral segment (VS) of the vertebral column in the female fetal goat, CR length : 28 cm. 1. Atlas; 2. Ventral lamina of transvers process of sixth cervical vertebra; 3. Intervertebral disc between seventh cervical and first thoracic vertebrae; 4. Transvers process of first lumbar vertebra; 5. Intervertebral disc between thirteen thoracic and first lumbar vertebrae; 6. Intervertebral disc between sixth lumbar and first sacral vertebrae7. First ventral sacral foramen; 8. Intervertebral disc between last sacral and first caudal vertebrae; 9. Last caudal vertebra, B. Vertebral body. Scale bar= 0.5 cm.

1. Length of each vertebral segment (length of the vertebral body and its caudal intervertebral disc, Fig. 1) according to the methods of Nourinezhad *et al*.

2. Regional lengths of the vertebral segments of entire vertebral column (sum of the length of the vertebral segments for each region).

3. Total length of the vertebral segments (sum of the total regional lengths of the vertebral segments of the vertebral column).

The length of each vertebral segment was measured three times using a digital caliper (Mitutoyo, Japan) to an accuracy of 0.05 mm and then the mean values were recorded. SPSS 16.0 for windows statistics software was used to compute the means and standard deviation values of all the parameters. All results were evaluated by applying one-way analysis of variance (ANOVA) test and post hoc Tukey test was used for comparing the data in age groups. The significance level was accepted at $P<0.05$. In addition, to investigate the differential growth of the various regions of the vertebral column, the relative lengths of the regions were computed and expressed as percentages of the entire column.

RESULTS

Numerical vertebral variations. The vertebral column of the fetal goat consisted of 39- 43 vertebrae. The vertebral column usually consisted of 7 cervical (C), 13 thoracic (T), 6 lumbar (L), 5 sacral, 8-12 caudal or coccygeal (Co) vertebrae, while the vertebral formula exhibited the lumbar and caudal vertebral variations. At 6-8 weeks, 7 lumbar (one goat), 8 caudal (two goats) and 9 caudal (two goats) vertebrae was documented. At 9-11 weeks, 8 caudal (one goat) and 10 caudal (three goats) vertebrae was found. At 12-14 weeks, 9 caudal (two goats) and 11 caudal (two goats) vertebrae was observed. At 15-17 weeks, 10 caudal (two goats) and 11 caudal (two goats) vertebrae was observed. At 18-20, 10 caudal (one goat) and 11 caudal (three goats) vertebrae was noted.

Total and regional lengths of the vertebral segments. The trend of the total lengths of the vertebral columns and the trend of the regional lengths of the vertebral segments of the vertebral column are shown in Figs. 2 and 3.

According to Table I, total and regional lengths of the vertebral segments differed significantly among the age groups except at 9-11 weeks and 15-17 weeks relative to their previous age groups. However, those variables in the lumbar region differed significantly, except in 15-17 weeks relative to the previous age group.

Differential growth of the regions of the vertebral column was calculated, and it was noted that the percentages of the total column occupied by the various regions vary from one stage to another (Table II). The total length of the vertebral segments of the vertebral column increased from 6-8 weeks until 18-20 weeks 361 %. The total length of the vertebral segments of the vertebral column in the cervical, thoracic, and lumbar regions was 330 %, 329 %, and 316 %, respectively, which was lesser than that of the total length of the vertebral column. However, the total length of the vertebral segments of the vertebral column in the sacral and caudal regions was 400 % and 624 %, respectively, which was greater than that of the total length of the vertebral segments of the vertebral column (Table I).

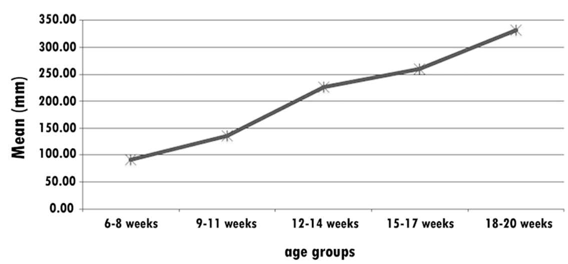

Fig. 2. The graph showing variations in the total lengths of vertebral column in different age groups of fetal goat.

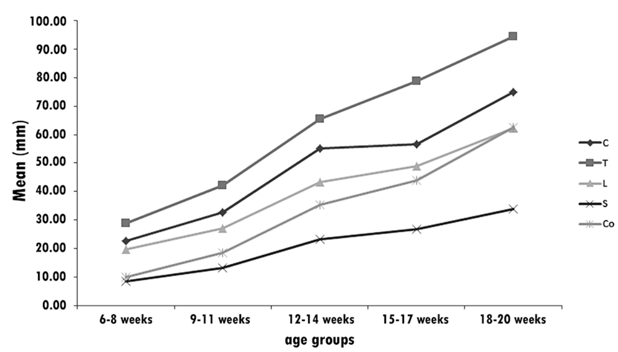

Fig. 3. The graph showing variations in the relative regional lengths of vertebral column in different age groups of fetal goat

According to Table I, the comparative percentage of the regional lengths of the vertebral segments in each region between the oldest and youngest age group showed, that the regional length of the cervical, thoracic, and caudal vertebral segments diminished, while the regional length of the sacral and caudal vertebral segments increased.

Table I. Means and SD and the percentage of the regional length in goat fetus in different age groups (mm).

	6-8 weeks	9-11 weeks	12-14 weeks	15-17 weeks	18-20 weeks
Cervical	22.68± 3.79^{a}	32.59± 1.69^{ab}	55.07±3.75^{c}	56.65±3.65^{cd}	74.96±9.75^{e}
	(25.34 %)	(24.38 %)	(24.76 %)	(22.22 %)	(22.83 %)
Thoracic	28.70±3.81^{a}	42.12±3.61^{ab}	65.40± 4.85^{c}	78.69±3.47^{cd}	94.55±11.63^{e}
	(32.07 %)	(31.51 %)	(29.41 %)	(30.87 %)	(28.97 %)
Lumbar	19.66±2.47^{a}	27.21±3.06^{ab}	43.36±3.26^{c}	48.86±3.26^{cd}	62.23±3.26^{e}
	(21/96 %)	(20.35 %)	(19.5 %)	(19.17 %)	(18.98 %)
Sacral	8.50±1.76^{a}	13.11±1.46^{ab}	23.11± 2.7^{c}	26.64±2.21^{cd}	34.01± 4.78^{e}
	(9.49 %)	(9.80 %)	(10.39 %)	(10.45 %)	(10.35 %)
Caudal	9.95±3.19^{a}	18.64±3.79^{ab}	35.40± 5.92^{c}	44.01±3.95^{cd}	62.58± 9.84^{e}
	(11.11 %)	(13.94 %)	(15.92 %)	(17.26 %)	(19.6 %)
Total	91.92±15.90^{a}	136`.09±7.98$^{a\,b}$	226.84±11.99^{c}	260.4±14.42^{cd}	332.25±41.39^{e}
	(100 %)	(100 %)	(100 %)	(100 %)	(100 %)

Means in a row with different small superscript letters (a, b, c, d, e) are statistically different ($p < 0.05$).

The longest regional vertebral segments of the vertebral column belonged to the thoracic region in all age groups followed by the cervical, lumbar, and sacral regions except at 18-20 weeks where the caudal region became longer than the lumber region (Table I).

Segmental growth pattern of the length of each vertebral segment for each vertebral region (Fig. 4). According to Table II, the length of all vertebral segments does not differ significantly between the 6-8 weeks and 9-11 weeks except in T9 and L2-L5.

The length of all vertebral segments differed significantly between 12-14 weeks and 9-11 weeks except in Co7-11(Table II).

The length of all vertebral segments differed significantly between 18-20 weeks and 15-17 weeks except in C7 and T2-6 (Table II)

The length of most vertebral segments did not differ significantly at 9-11and 15-17 weeks relative to their previous groups except at T9, L2-5 and L4 (in 9-11 weeks) and T9-13(in 15-17 weeks, Table II).

In the cervical region, the length of the vertebral segments gradually declined from C2 to C7. In the cervical region of all the age groups, C2 and C7 were the longest and the shortest segments, respectively (Table II).

In the thoracic region, the length of the vertebral segments gradually declined and then gradually increased. In the thoracic region of all the age groups, T13 was the longest vertebral segment. The shortest was T8, T7, T6, and T5 in age group 6-8, 9-11, 12-14, 15-17, and 18-29 weeks, respectively (Table II).

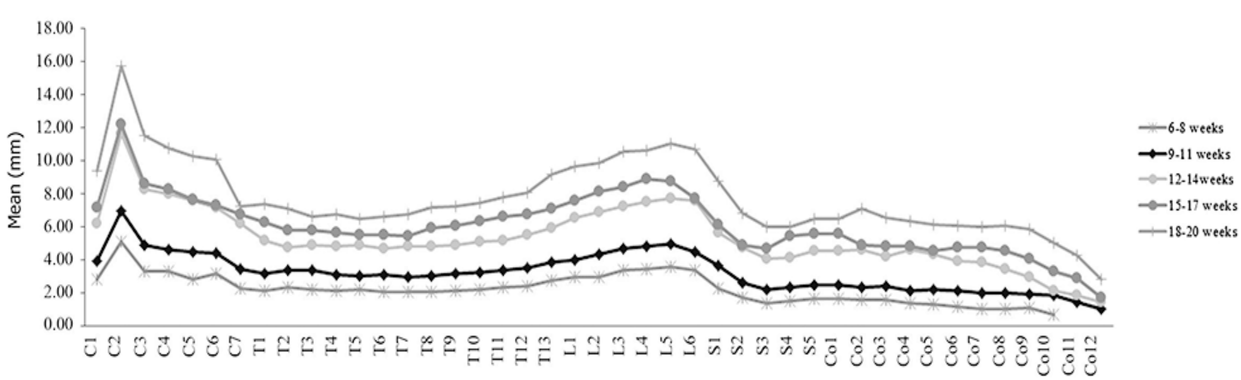

Fig. 4. The graph showing variations in the segmental lengths of vertebral column in different age groups of fetal goat

In the lumbar region, the length of the vertebral segments decreased up to the T4 or T5 and or T6 except at 6-8 weeks; thereafter they gradually became longer. The length of the vertebral segments gradually increased up to L4 or L5; thereafter they gradually became shorter. In the lumbar region of the all the age groups, L1 and L5 were the shortest and the longest, respectively expect at age group 15-17 weeks in which L4 was the longest (Table II).

In the sacral region, the length of the vertebral segments decreased up to the S3; thereafter they gradually became longer. In the sacral region of all the age groups, S1 and S3 were the longest and shortest, respectively (Table II).

In the caudal region, the length of the vertebral columns did not exhibit a constant regional growing trend. In the caudal region of all the age groups, Coccygeal (Co) 12 was the shortest. Co2 (in 6-8 weeks), Co3 (in 12-14 weeks), and Co1 (in 15-17 and 18-29 weeks) were the longest vertebral segment (Table II).

Table II. Means and SD of length of vertebral segments of vertebral column in goat fetus (mm)

	6-8 weeks	9-11weeks	12-14 weeks	15-17 weeks	18-20 weeks
C1	2.79±0.27^{a}	3.92±0.13^{ab}	6.22±1.25^{c}	7.15±1.38^{cd}	9.37±1.15^{e}
C2	5.11±0.96^{a}	6.98±0.64^{ab}	1.66±1.11^{c}	12.18±0.61^{cd}	15.73±1.68^{e}
C3	3.31±0.73^{a}	4.85±0.43^{ab}	8.29±0.65^{c}	8.63±1.09^{cd}	11.52±1.28^{e}
C4	3.27±0.44^{a}	4.85±.24^{ab}	8.01±0.77^{c}	8.24±0.60^{cd}	10.74±1.42^{e}
C5	2.79±0.70^{a}	4.47±.0.46^{ab}	7.59±0.64^{c}	7.660.31^{cd}	10.29±1.52^{e}
C6	3.14±0.60^{a}	4.37±0.29^{ab}	7.15±0.37^{c}	7.30±0.64^{cd}	10.06±1.74^{3}
C7	2.28±0.44^{a}	3.42±0.29^{ab}	6.16±0.62^{c}	6.77±0.54^{cd}	7.26±1.64^{cde}
T1	2.09±0.52^{a}	3.14±0.23^{ab}	5.19±0.73^{c}	6.28±0.78^{cd}	7.35±1.48^{e}
T2	2.32± 0.23^{a}	3.36±0.32^{ab}	4.76±0.77^{c}	5.81±0.32^{cd}	7.13±1.04^{de}
T3	2.18±0.32^{a}	3.33±0.29^{ab}	4.91±0.39^{c}	5.78±0.39^{cd}	6.60±1.13^{de}
T4	2.08±0.32^{a}	3.12±0.32^{ab}	4.81±0.52^{c}	5.63±0.34^{cd}	6.77±1.16^{de}
T5	2.17±0.29^{a}	3.05±0.26^{ab}	4.91±0.67^{c}	5.53±0.52^{cd}	6.47±0.80^{de}
T6	2.06±0.27^{a}	3.06±0.26^{ab}	4.66±0.39^{c}	5.51±0.24^{cd}	6.61±1.03^{de}
T7	2.05±0.36^{a}	2.97±0.26^{ab}	4.78±0.48^{c}	5.43±0.35^{cd}	6.73±1.03^{e}
T8	2.03±0.25^{a}	3.01±0.28^{ab}	4.84±0.17^{c}	5.89±0.53^{cd}	7.16±0.84^{e}
T9	2.10±0.22^{a}	3.15±0.15^{ab}	4.90±0.15^{c}	6.04±0.48^{d}	7.21±0.71^{e}
T10	2.17±0.21^{a}	3.20±0.29^{ab}	5.06±0.07^{c}	6.32±0.67^{d}	7.47±0.82^{e}
T11	2.30±0.28^{a}	3.36±0.27^{ab}	5.16±0.14^{c}	6.62±0.66^{d}	7.81±0.85^{e}
T12	2.41±0.27^{a}	3.51±0.49^{ab}	5.50±0.29^{c}	6.74±0.53^{d}	8.09±0.76^{e}
T13	2.75±0.68^{a}	3.86±0.64^{ab}	5.93±0.35^{c}	7.12±0.84^{d}	9.15±0.48^{e}
L1	2.97±0.22^{a}	4.00±0.33^{ab}	6.51±0.52^{c}	7.60±0.79^{cd}	9.64±0.57^{e}
L2	2.95±0.43^{a}	4.34±0.54^{ab}	6.86±0.56^{c}	8.10±0.76^{cd}	9.84±0.57^{e}
L3	3.38±0.36^{a}	4.67±0.75^{ab}	7.22±0.61^{c}	8.38±0.56^{cd}	10.44±0.33^{e}
L4	3.40±0.38^{a}	4.84±0.80^{ab}	7.49±0.50^{c}	8.90±0.52^{d}	10.59±0.27^{e}
L5	3.57±0.48^{a}	4.93±0.42^{ab}	7.71±0.61^{c}	8.72±0.90^{cd}	11.04±0.56^{e}
L6	3.39±0.75^{a}	4.44±0.33^{ab}	7.57±0.66^{c}	7.70±0.84^{cd}	10.69±1.12^{e}
S1	2.28±0.58^{a}	3.62±0.62^{ab}	5.61±0.65^{c}	4.91±0.32^{cd}	8.78±1.40^{e}
S2	1.72±0.36^{a}	2.60±0.26^{ab}	4.77±0.50^{c}	4.79±0.25^{cd}	6.80±0.68^{e}
S3	1.38±0.27^{a}	2.17±0.34^{ab}	4.55±0.34^{c}	4.80±0.68^{cd}	5.98±0.99^{e}
S4	1.50±0.36^{a}	2.29±0.54^{ab}	4.15±0.62^{c}	4.51±0.35^{cd}	5.99±0.98^{de}
S5	1.62±0.49^{a}	2.43±0.51^{ab}	4.52±0.65^{c}	4.74±0.40^{cd}	6.47±0.92^{de}
Ca1	1.53±0.51a	2.29±0.42^{ab}	4.57±0.67^{c}	4.91±0.32^{cd}	7.12±1.03^{e}
Ca2	1.57±0.52a	2.42±0.41^{ab}	4.17±0.26^{c}	4.79±0.25^{cd}	6.51±0.80^{e}
Ca3	1.33±0.31^{a}	2.11±0.08^{ab}	4.59±0.65^{c}	4.80±0.68^{cd}	6.34±0.84^{e}
Ca4	1.25±0.27^{a}	2.15±0.34^{ab}	4.31±0.43^{c}	4.51±0.35^{cd}	6.13±0.84^{e}
Ca5	1.13±0.33^{a}	2.13±0.28^{ab}	3.90±0.43^{c}	4.74±0.40^{cd}	6.06±0.83^{e}
Ca6	1.02±0.31^{a}	1.95±0.17^{ab}	3.81±0.39^{c}	4.74±0.43^{cd}	5.99±0.82^{e}
Ca7	0.99±0.33^{a}	1.94±0.18^{ab}	3.42±0.76^{bc}	4.57±0.46^{cd}	6.05±1.07^{e}
Ca8	1.05±0.16^{a}	1.93±0.21^{ab}	2.93±1.04^{bc}	4.02± 0.41^{cd}	5.82±1.00^{e}
Ca9	0.69±0.25^{a}	1.82±0.29^{ab}	2.10±1.03^{abc}	3.26±0.54^{bcd}	5.05±0.95^{e}
Ca10	-	1.41±0.29^{ab}	1.84±0.94^{bc}	2.84±0.13^{bcd}	4.27±0.86^{e}
Ca11	-	1.02±00.0^{ab}	1.41±0.88	1.68±0.32	2.77±0.59
Ca12	-	-	-	-	1.56±0.63

Means in a row with different small superscript letters (a, b, c, d, e) are statistically different ($p < 0.05$).

DISCUSSION

Numerical vertebral variations. The present findings confirm published reports regarding the normal caprine vertebral formula (Barone, 1976; Nickel *et al*.). The most frequent variations of this formula, cited in the literature, are the presence of 12 thoracic (Nickel *et al*.), 5-7 lumbar (Nickel *et al*.) and 4 or 6 sacral (Barone; Nickel *et al*.) vertebrae. In this study, the thoracic and cervical regions of the vertebral column did not present numerical variations but the presence of 7 lumbar was noted only in one goat. The number of the segmental vertebrae in the caudal region of the fetal goat also was most often altered, which correspond with the findings of previous publications (Barone).

Total and regional length of the vertebral segments. There is a general trend of increasing segmental and regional initial growth, and there is a relatively significant increase in growth rate caudally along the column during fetal period. This is supported by the accounts of Noden & de Lahunta (1985) in the domestic animals with increasing gestational age, the caudal aspect of the fetus exhibits extensive growth and elongation. On the other hand, the segmental growth of the vertebral column relates to the liner disposition of other anatomical systems. Accordingly, such an elongation of the caudal region may be related to the cranial movement of the spinal cord and kidney with reference to the vertebral column during prenatal development.

The growth rate of regional vertebral length seems to be different among the rodents, humans and domestic animals. Bagnall *et al*. (1979) reported, by radiography of the human spine, that from 8 weeks the longest vertebral column belonged to the thoracic region followed by the lumbar, cervical, and sacral regions. Muller & O'Rahilly (1986) by using serial sections of human embryos, documented that the relative length of the vertebral bodies of the cervical and coccygeal regions decreased, the thoracic and lumbar regions increased, and the sacral region was more or less constant during embryonic development. Bergmann *et al*. (2006) recorded that at birth, the rat thoracic region is longest, followed by the caudal, lumbar, cervical and sacral. In the present study, at the oldest fetuses the thoracic region was longest, followed by the cervical, caudal, lumbar, and sacral. Therefore, although the vertebral lengths of the cervical region essentially varies among the fetal goats, humans, and rodents, the cervical region always grows to be among the longest vertebrae in goat during the fetal period. Previous morphometric studies affirmed that the cervical spine was markedly different between the ruminants (sheep or deer) and humans (Wilke *et al*.; Kumar *et al*.).

Like those of the present study, in adult domestic animals, the thoracic vertebral column is the longest, followed by the cervical, caudal, lumbar, and sacral (Barone). Thus, it seems that the regional growth rates of the vertebral length during prenatal development determine those in postnatal development. This assumption is confirmed by findings of Bergmann *et al*., that growth from birth to adulthood is, then allometric, providing a differently proportioned adult when compared to the neonate.

Such differences in growth rate of regional lengths of the vertebral column in fetal goats may be adapted to its differential locomotor activities during the postnatal period. The connection between the trunk and the head is formed by the cervical vertebral column and in all species, it is much more mobile than the lumbar and thoracic part of vertebral bridge. The cervical vertebral column and the neck are used in the multitude of movements and adjustment of the head that are involved in feeding, fighting and grooming (Nickel *et al*.). The ruminants have 13 thoracic vertebrae to contribute to the disproportionately large cervical vertebrae and marked lordosis at cervico-thoracic junction and they have 6 lumbar vertebrae which may be associated with quadruped hip, which generate greater forces during running as compared to human beings (Kumar *et al*.).

Longest and shortest vertebral segment. According to Table III, a different developmental pattern emerges when vertebral segment or bony part of the vertebral column for each region are compared.

In the cervical region, the longest and shortest vertebral segment or bony part of vertebral column exhibited interspecific variations. However, the longest vertebral segment in the fetal goat was constant with that of the adult sheep (Table III).

According to Table III, in the thoracic region, the longest vertebral segment or bony part of the vertebral column of various species was the last vertebrae, whilst the shortest vertebral segment differed among various species. However, the shortest vertebral segment of the thoracic region in the fetal goat was consistent with that of the fetal sheep (Nourinezhad *et al*.), adult sheep (Nickel *et al*.), and adult deer (Kumar *et al*.). In addition, it seems that with increasing fetal age, the shortest vertebral segment of the fetal goat and sheep appeared in more cranial thoracic level (T5 or T6).

In the lumbar, the longest vertebral segment or bony part of the vertebral column in various species belonged to one before the last. The shortest vertebral segment or bony part of the vertebral column belonged to the first vertebra or last one. However, previous authors disagree among themselves

Table III. Compression of the longest and the shortest vertebral segment or osseous part of the vertebral segment between present study and other reported species.

	Shortest vertebral segment or bony part of vertebral segment	Longest vertebral segment or bony part of vertebral segment
C2		This study, sheep (Wilke *et al.,* 1997)
C3	Monkey :without measuring C1 and C2 (Tominaga *et al.,* 1995)	
C6	Human: without measuring C1 and C2 (Panjabi et al., 1991a)	
C7	This study, sheep (Wilke *et al.,* 1997)	Human: without measuring C1 and C2 (Panjabi *et al.,* 1991a) and Monkey: without measuring C1 and C2 (Tominaga *et al.,* 1995)
T11	Human (Panjabi et al., 1991a; Kumar *et al.,* 2000)	
T5	This study (18-20 weeks)	
T6	This study (12-14 weeks and 15- 17 weeks), sheep (Wilke *et al.,* 1997)	
T7	This study: 9-11 and 15-17 weeks, deer (Kumar *et al.,* 2000), fetal sheep:6-8,9-11,12-14weeks (Nourinezhad *et al.,* 2013)	
T8	This study (6-8 weeks), fetal sheep : 6-8 weeks (Nourinezhad *et al.,* 2013)	
T12		Human (Kumar *et al*., 2000; Panjabi *et al.,* 1991b)
T13		Fetal sheep (Nourinezhad *et al.,* 2013), deer (Kumar *et al.,* 2000), sheep (Wilke *et al.,* 1997)
L4	This study: all age groups except 15-17 weeks, deer (Kumar *et al.,* 2000) sheep, and human (Wilke *et al.,* 1997)	
L2		Human (Panjabi *et al*., 1992)
L4		This study: 15- 17 weeks, human (Berry *et al.,* 1987), deer (Kumar *et al.,* 2000)
L5	Human (Berry *et al.,* 1987)	This study: all age groups except 15-17 weeks, sheep (Wang *et al.,* 1997), deer (Kumar *et al.,* 2000)
L6	sheep (Wilke *et al.,* 1997), sheep (Wang *et al.,* 2015), deer (Kumar *et al.,* 2000)	
L7	sheep (Wilke *et al.,* 1997)	
S1		This study
S3	This study	
Ca1		This study: 15-17, 18-20 weeks
Ca2		This study: 6-8, 9-11 weeks
Ca3		This study: 12-14 weeks
Ca12	This study	

on the longest and shortest vertebral segments of lumbar region within the adult humans, sheep, and deer (Table III).

In the sacral region, the longest vertebral segment or bony part of the vertebral column of different species belonged to S1, whilst the shortest vertebral segment or bony part of the vertebral column belonged to the last one or the second last vertebra (Table III).

In the caudal region, the longest vertebral segment or bony part of the vertebral column of various species belonged to the first three, whilst the shortest vertebral segment or bony part of the vertebral column belonged to the last one (Table III).

In conclusion, the longest and shortest vertebral segments of vertebral column in the fetal goat were extremely constant with those of other reported animals and humans (Table III).

There are substantial differences between lengths of the vertebral bodies of different regions of the column Nickel *et al*. According to them, the length of single vertebral body was longest in the cervical region, followed by the lumbar and thoracic regions, respectively, whereas in this study, the longest was almost the lumbar, followed by the cervical and thoracic regions, receptively. Such a difference in the length of the single vertebral body between the prenatal and postnatal development may come from the size of somites prenatally.

For example, in mice, the lumbar somites are larger and provide faster axial elongation (Bergmann *et al*.).

Segmental and regional growth patterns of the vertebral segments. The length of the cervical bodies gradually diminished from the 3rd to the 7th in the domestic mammals (Nickel *et al*.), sheep, goats, horses, dromedary camels (Barone), monkeys (Tominaga *et al*., 1995), and adult sheep (Wilke *et al*.) which correspond with the results of this study. However, unlike those of the above mentioned species, the length of the cervical bodies gradually increased from superior to inferior in humans (Nickel *et al*.), and in neonatal rats (Bergmann *et al*.), or as some authors declared that the length of the cervical bodies gradually declined from 3th to 5th or 6th and thereafter, increased (Francis, 1995; Panjabi *et al*., 1991a, 1991b, 1992).

The length of the thoracic bodies increased from the cranial to the caudal in the sheep, goats, and horses (Barone), and humans (Nickel *et al*.; Kumar *et al*.). On the contrary, the length of the thoracic bodies gradually diminished to the middle of the region; thereafter they increased and became longer than cranial thoracic region in the ruminants (Nickel *et al*.), fetal sheep (Nourinezhad *et al*.), and adult sheep (Wilke *et al*.) similar to that of the present findings in the fetal goats. This is further supported, by the ultrasonographic findings, that the length of the first sixth thoracic vertebrae gradually increased during fetal goats (Kandiel *et al*.).

In this study, the length of the lumbar vertebral segments increased from the first vertebra to one before last; thereafter they declined which concurred with the previous findings in the carnivores (Nickel *et al*.), pigs (Barone), deer (Kumar *et al*.), adult deer and sheep (Wang *et al*.) adult sheep (Wilke *et al*.), sheep, goats, horses (Barone), and humans (Nickel *et al*.; Kumar *et al*.). However, recent studies demonstrated that the vertebral length of the lumbar region in humans varies viable in segmental growth patterns (Wang *et al*.).

Based on the above detailed discussion and in agreement with findings of Bagnall *et al*. (1977), we suggest that inter- and intraspecific variations of the segmental and regional growth patterns of the vertebral column, development and function of particular groups of muscles, fetal movements, may be related to the pattern of ossification centers in the vertebral column.

The main conclusion to be drawn from the above data is that the longest and shortest of the vertebral segment as well as regional trend of length of the bodies of the caudal thoracic and cranial lumbar regions in fetal goats are similar to that in adult sheep and humans. This is supported by the findings of Wilke *et al*., that similarities in regional trend and length of bodies in sheep and human spine are strongest in the thoracic and lumbar regions. Accordingly, our research yields important results that may be useful for biomechanical experiments related to the gross structure of the thoracic or lumbar spine, that contemplate the use of goat as a new model for the human spine.

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NOURINEZHAD, J.; BAMOHABAT, S.; MAZAHERI, Y. & KHAZAEEL, K. Desarrollo morfométrico de los segmentos vertebrales de la columna vertebral en cabra (capra hircus) durante el período fetal. *Int. J. Morphol., 35(2)*:506-514, 2017.

RESUMEN: Entender el crecimiento fetal normal de la columna vertebral entre las especies, proporciona una base para establecer valores de referencia en la evaluación del desarrollo corporal y la estimación de la edad fetal por ultrasonografía. Las cabras se utilizan frecuentemente en investigaciones biomédicas perinatales y son consideradas clave en el estudio del desarrollo esquelético. Este estudio se realizó con el objetivo de determiner el crecimiento de longitud de la columna vertebral a nivel segmentario, regional y total de la columna vertebral en cabras fetales durante diferentes etapas gestacionales. La longitud de cada segmento vertebral de 25 fetos de cabra, con edades comprendidas entre las 6 y 20 semanas se midió utilizando un calibre digital. Nuestro estudio demostró diferencias entre varias edades fetales en términos de tasa de crecimiento regional, segmentario y total de longitud de los segmentos vertebrales Con el aumento de la edad fetal, la longitud relativa de los segmentos vertebrales de las regiones cervical, torácica y lumbar disminuyó, mientras que las regiones sacras y caudales aumentaron en longitud relativa. Las vértebras torácicas fueron las más largas seguidas por las regiones cervical, lumbar, caudal y sacral excepto en los fetos más antiguos donde la región caudal se hizo más larga que la región lumbar. Aunque los segmentos vertebrales más largos y más cortos en las regiones cervical y lumbar fueron consistentes entre los grupos de edad, la tendencia de crecimiento segmentario de las regiones vertebrales fue variable. En base a estos resultados, las longitudes relativas de columna vertebral fueron esencialmente diferentes entre cabras fetales, humanos y ratas neonatas. También existe una tendencia general de aumento del crecimiento inicial segmentario y regional, como tambien un aumento relativamente significativo en la tasa de crecimiento a lo largo de la columna durante el período fetal. Esta investigación arroja importantes resultados que también pueden ser útiles para futuros estudios ortopédicos que contemplan el uso de la cabra como un nuevo modelo para la columna vertebral humana.

PALABRAS CLAVE: Crecimiento segmentario; Vertebra; Morfometría; Feto Cabra; Desarrollo prenatal.

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