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▶ To cite this version:

Josephine Roels, Roy Hassoun, M Massenzio, S Ronel, Y Lafon, et al.. A morphometric analysis of thoracolumbar vertebrae in goat by computed tomography. Veterinary and Animal Science, 2022, 15, pp.100233. 10.1016/j.vas.2022.100233 . hal-04395406

HAL Id: hal-04395406 https://vetagro-sup.hal.science/hal-04395406v1

Submitted on 22 Jul2024

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Version of Record: https://www.sciencedirect.com/science/article/pii/S2451943X22000047 Manuscript_e35d7c2c59d1253b4cc1de9bcd2b2da2

1 A morphometric analysis of thoracolumbar vertebrae in goat by

2 computed tomography.

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18 Abstract

19 The goat spine is widely used as an animal model for preclinical research in human medicine to test 20 new spinal implants and surgical procedures. Therefore, precise morphometric data are needed. This 21 study aims to provide morphometric data of the goat thoracolumbar vertebrae and to define the 22 parameters/characteristics of the optimum implantation corridors for pedicle screws in the 23 thoracolumbar spine in goat. Eleven 36-month-old adult alpine goats were included in this study, and a 24 sample of 198 vertebrae was measured. Subsequently, transverse and sagittal images were obtained 25 using a multi-detector-row helical computed tomography (CT) scanner. Measurements of the vertebral 26 bodies (ventral body width VBW, ventral body depth VBD, ventral body height ventral VBHv, ventral 27 body high dorsal VBHd, spinal canal depth SCD, spinal canal width SCW), pedicles (pedicle length 28 PDL, pedicle width PDW, pedicle angle PA and pedicle axis length PAL), intervertebral disc (DT) 29 and transverse process length (TPL) were performed with dedicated software. The vertebral bodies 30 and the spinal canal were wider than deep, mostly evident in the lumbar region. The intervertebral 31 discs were as much as 65.7% thicker in the lumbar spine than in the thoracic spine. The pedicles were 32 longer than wide over the thoracic and lumbar spines. The insertion angles in pedicle were 33 approximately 30° for the T2-T4 segment, 25° for the T5-T6 segment, 23° for the T6 to T11 segment, 34 20° for T11 to L3, 25° for L4 and 30° for L5 and L6. In conclusion, the generated data can serve as a 35 CT reference for the caprine thoracolumbar spine and may be helpful in using the goat spine as an 36 animal model for human spinal research.

37

38 **Key-words:** goat, morphometric, spine, computed tomography, pedicular screw

39

40 Introduction

Spinal abnormalities in humans have major effects on skeletal growth and the development of
various organs. Several studies are interested in developing new surgical techniques to correct these
abnormalities.

44 The use of human specimens is the best way to mimic the physiological situation, but many 45 difficulties are associated with their use, such as the restricted number of fresh healthy cadavers. 46 Several healthy cadavers are needed to eliminate the wide scattering effect associated with biological 47 variability (3). Thus, an appropriate animal model should be used to mimic the human spine with 48 chosen biomechanical characteristics and anatomical dimensions that are as similar as possible to 49 those in humans. In addition, precise geometrical data of animal models are needed for mathematical 50 models (11,26). The similarity of the anatomical characteristics of the goat spine to the human spine 51 and the rapid growth observed in goats between the ages of 6 weeks and 8 months and between 52 childhood and maturity in humans make caprine models an interesting replacement (4,6,10,20). 53 Moreover, several in vitro and in vivo studies have used the caprine model as an animal model for 54 orthopedic and neurological research. However, in those studies, neurological trauma and loss of 55 animals due to poor implant positioning because of an under/over estimation of pedicle angulation 56 caused time and cost losses. These facts highlight the importance of spinal monitoring and 57 morphometrical analysis of the goat spine (15,19-20,27).

Computed tomography (CT), a noninvasive imaging technique, has been used worldwide in humans and in animals as a gold standard to perform in vivo morphometric analysis of the spine and to determine variations in the vertebrae size and shape (1,12,18). Morphometric studies have many limiting factors, such as measurement accuracy and viewer control settings, factors that should be assessed.

Morphometry of the goat thoracolumbar spine is important for studies that contemplate its use. Design strategies, surgical techniques and interpretation of results derived from such studies require morphometry. The aim of this study is to provide quantitative reference values and a complete comprehension of the pedicle morphology and angulation in healthy adult caprine spine models using computed tomography.

68

69 Materials and methods

70 Animals

This study was approved by the institutional animal care and use committee at the School of VetAgroSup. Eleven adult alpine goats without any history or clinical signs related to spinal diseases were
included in this study. All goats came from the same batch. The mean body weight of goats was 42.5
kg.

75

76 Computed tomography (CT) Examination

The goats were euthanized for other experimental studies unrelated to this study. The goats were positioned in dorsal recumbency in a perpendicular position of the spine relative to the radiographic beam. CT scans were performed from the cranial aspect of T2 to the caudal aspect of L6 with a multidetector-row helical CT unit General Electric's, Brightspeed 16 elite (GE Healthcare, Buckinghamshire, England, Great Britain).

The technical settings were 120 kV, 150 mA, 1-second tube rotation and 0.625 pitch. The data were reconstructed to a transverse, sagittal and frontal image series with slice thickness ranging between 0.2 and 0.8 mm using a high-frequency image reconstruction algorithm (Osirix Imaging Software). Transverse images were reconstructed parallel to the third level of the cranial endplate of the vertebral body, whereas sagittal images were reconstructed at the midsagittal plane of the vertebra to measure the vertebral body and intervertebral disc dimensions.

Three parameters were measured from the sagittal images, and eight parameters were measured from the transverse images for each spinal level. These parameters were measured as described in the human and veterinary literature (14,28). In addition, the parameters of the implantation corridor for pedicular screws were measured from the transverse images as described by McLain (16).

The morphometrical parameters obtained from transverse images included vertebral body width (VBW), which is the distance between the lateral border measured at the third cranial endplate of the vertebral body, and vertebral body depth (VBD), reflecting the distance between the dorsal and ventral borders of the vertebral body. Spinal canal width (SCW) and depth (SCD) were obtained by measuring the distance between the axial pedicle cortical and the dorsal border of the vertebral body to the lamina at the midline, respectively. Transverse process length (TPL) was assessed by measuringthe distance between the two tips of the transverse process (Figure 1).

100

101 The morphometric parameters obtained from sagittal images included the distance between the 102 cranial and caudal endplates of the vertebral body at the dorsal margin, termed the vertebral body 103 height dorsal (VBHd); the same distance at the ventral margin was termed the vertebral body height 104 ventral (VBHv). Disc thickness (DT) was measured at the mid-level of the intervertebral disc (Figure 105 2).

106

107 Parameters concerning the implantation corridor for the pedicular screw were assessed by 108 measuring the pedicle width (PDW), pedicle length (PDL), pedicle angle (PA) and pedicle axis length 109 (PAL) on transverse images (Figures 3 and 4). PDW was defined as the narrowest part of the pedicle. 110 In the thoracic vertebrae, PDL reflects the distance between the dorsal pedicle cortex and the line 111 perpendicular to the vertebral midline (tangent to the ventral border of the spinal canal). In the lumbar 112 vertebrae, PDL reflects the distance between the dorsal pedicular cortex and the junction of the ventral 113 border of the transverse process. PAL was measured from the dorsal cortex of the articular facet to the 114 midpoint of the ventral vertebral body cortex. Finally, PA was the angle between the PAL and the 115 vertebral sagittal midline.

116

117 Statistical analysis

118 Descriptive data are presented as means and standard deviations (SDs). Assessment of intraobserver 119 reliability was calculated by randomly selecting three goats in which measurements were performed 120 four times by the same operator. A coefficient of variation (CV) was used to assess reliability. The 121 Mann-Whitney/Two-tailed test was used to determine differences between the vertebral levels for each 122 parameter. Statistical analysis was performed with dedicated available software (Microsoft Excel 123 2010, XLSTAT ®). The level of significance was set at p < 0.05, and CV<5% was considered 124 acceptable.

126 **Results**

A total of 198 vertebrae (132 thoracic vertebrae and 66 lumbar vertebrae) from 11 mature goats' thoracolumbar vertebral columns were measured. CT images revealed that all the goats had 6 lumbar vertebrae and 13 thoracic vertebrae (the first thoracic vertebra was not measured in this study). Assessment of intraobserver reliability revealed a high level of reliability (Table 1), with values ranging between 0.06% and 3.13%. Tables 2, 3, and 4 present the means and standard deviations of the CT measurements in the thoracolumbar spines of the 11 goats.

- 133
- 134 Vertebral body measurements (transverse and sagittal view)

Values and variation of the ventral body width (VBW) are summarized in Table 2 and Figure 5. The value of VBW was greater for T2, T3 and for L5 and L6. VBW was significantly higher in the lumbar segment compared to the thoracic segment (p=0.02). The value of the ventral body depth (VBD) was fairly constant around 12 mm in the thoracic and lumbar segment (Table 2 and Figure 5).

In the thoracic region, VBHd was constant, at approximately 22 mm, and then increased steadily from T9 until T13 to reach 29 mm. In the lumbar region, VBHd was fairly constant at approximately 34 mm, except at L6, where it was smaller at 29.6 mm. Similar to VBHd, VBHv was smaller at the level of L6 (26.7 mm). VBHv was constant at approximately 21 mm from T2 to T9 and then increased from T10 to T13. VBHd was always larger than VBHv in both the lumbar and thoracic regions (Table 2 and Figure 6).

DT ranged between 1.71 and 2.83 mm in the thoracic region, while in the lumbar region, it showed greater values ranging between 2.67 and 3.32 mm (Table 2). The largest point of DT was between the fifth and the sixth lumbar vertebrae. In the lumbar segment, DT was 1 mm thicker than in the thoracic spine.

149

150 Spinal canal and transverse process measurements (transverse view)

Table 3 and Figure 7 show that T2, T3, T4 and L4, L5, L6 vertebrae share the maximal spinal
canal width (SCW) and depth (SCD). Concerning transverse process length, it was constant at

approximately 41 mm in the thoracic region. In the lumbar region, the value measured twice the length

154 (around 90mm). The maximum TPL was observed in L4 and L5 (Table 3).

155

156 *Pedicle parameters (transverse view)*

The pedicle parameters are listed in Table 4; interesting variations are reported in Figure 8. Pedicle width (PDW) was significantly greater in the lumbar vertebrae, ranging from 5.20 to 8.10 mm, than PDW in the thoracic vertebrae, which ranged from 4.49 to 6.04 mm (p=0.002). PDW reached its maximum at the sixth lumbar vertebra (8.10) and its minimum at T13 (4.49).

161 Pedicle length (PDL) showed a significant difference (p=0.0001) between the thoracic and 162 lumbar vertebrae, reaching its maximum at L3 and its minimum at T11. In the thoracic segment, the 163 PDL values ranged from 8.43 to 11.11 mm, and in lumbar segment, the PDL values ranged from 11.37 164 to 12.28 mm. Pedicle axis length (PAL) showed a significant difference (p=0.0008) between the 165 thoracic and lumbar vertebrae, reaching its maximum at the L6 level and its minimum at T2. PAL 166 ranged between 29.1 and 32.5 for the lumbar vertebrae and between 24.3 and 27.7 for the thoracic 167 vertebrae. Pedicle angle (PA) showed higher value between T2 and T3 (around 30 degrees) and 168 between the L5-L6 segment (around 30 degrees to reach its maximum point of 33.4 degrees at L6). 169 T12 and T13 showed the lowest pedicular angulation (around 20 degrees). PA value was around 25 170 degrees for T4-T5, 23 degrees between T6 and T11, 22 degrees between L1 and L3 and at 24 degrees 171 for L4.

- 172 In Table 5, mean values and standard deviation for each parameter are summarized for the173 thoracic and lumbar segment.
- 174

175 **Discussion**

176 Several in vitro studies have used the goat as an animal model for orthopedic spinal research. 177 The goat is particularly interesting because of the similarity of its spine to the human spine and the 178 rapid growth observed in goats between the ages of 6 weeks and 8 months, which mimics human 179 growth. Moreover, goats are readily available, inexpensive, easy to handle and well accepted as an 180 ethical animal model. Therefore, precise morphometric data of the goat spine are mandatory to 181 improve the quality of implant fixation and implantation and, thus, to avoid loss of the animal (5-6). In 182 a previous study, eleven goats were used to develop a Shilla-like growth stem (15). During the 183 experiment, one goat became paraplegic after the insertion of a pedicular screw. In another study 184 about development of a scoliosis model by Zhang et al., 28% (4/14) of goats were excluded from the 185 results due to a failure in pedicular screw implantation (15,27). In this last study, pedicular screws 186 were inserted between T6-T7, with an angulation of 30 degrees in the sagittal plane and an angulation 187 of 40 degrees at the lumbar level. In the current study, the implantation corridor for the pedicle screws 188 at the level of T6-T7 was 23 degrees and did not exceed 30 degrees in the lumbar region. These facts 189 explain the needed CT reference values to establish safe implantation corridors for pedicular screws in 190 the caprine thoracolumbar spine.

191 In humans, Roy-Camille *et al.* recommended that the pedicle screw should be inserted in a 192 straight (vertical) direction (22). It is interesting to note that the pedicle angulation in goats is more 193 oblique than in humans. Therefore, using a straight screw insertion technique could lead to a high 194 misplacement rate in goats. Thus, an oblique trajectory should be used. This conclusion was also 195 reported in sheep (10).

196 The results of the present study show that the spinal canal and vertebral bodies in goats are 197 wider than deep, especially in the lumbar region. However, the spinal canal tends to have a 198 comparable width and depth in the caudal thoracic region. The intervertebral discs are the thickest in 199 the lumbar region. Pedicles are higher and longer than wide throughout the entire thoracic and lumbar 200 spine. The disc thickness is 65.7% thicker in the lumbar vertebrae than in the thoracic vertebrae. A 201 thicker disc offers better mobility than a thinner disc (8). Conversely, transverse processes are longer 202 in the thoracic region than in the lumbar region. The latter findings may explain the limited lateral 203 flexion and axial rotation of the lumbar region (25).

In humans, spinal canal dimensions have an influence on movement upon the coronal axis of the spine; for instance, larger dimensions facilitate bending movement (9,23). In the current study, the dimensions of the spinal canal were maximal at two points: L6 and T8. Based on these results, we expect the maximum flexion point to be at L6 and the minimal flexion point to be at T9. No biomechanical study of this nature has been carried out on the goat spine. To our knowledge, this isthe first report of this value in the goat spine.

In a study conducted by Qui *et al.*, eleven goats with an average weight of 28 kg underwent magnetic resonance imaging for the caudal thoracic spine (T9-T13), and morphometrics data were measured (19). As an example, the T10 body height value was 23.7 mm vs 23 mm in the current study, which confirms the reliability of the results obtained. Moreover, the age of the goats used in the study of Qui *et al.* ranged between 26 and 32 months, while in our study, the age average was 48 months. These results support the fact that the vertebral column of goats reaches its maximum growth size between 26 and 32 months (19).

In humans, pedicles represent a maximum resistance site for the placement of screws. The trabeculae in the pedicles seem to be thicker and stronger than in the vertebral body. In addition, the pedicular cortex is thicker, allowing an effective holding of screws (12); thus, the pedicular morphometry plays an important role in vertebral fixation. The screw diameter should be 80% of the pedicle diameter (28). Therefore, the current study provides the precise morphometric data needed for the use of goats as a research model for pedicular fixation.

To our knowledge, this is the first report of the pedicular implantation corridors of the entire thoracolumbar goat spine (except for the first thoracic vertebra T1). However, the majority of cases concern the segment T3-L5 due to the complexity of the surgical approaches for T1, T2, T3 and L6. Their description has little relevance for pedicle attachment but is provided to fill in the lack of the morphometric data for goats in the literature. Plus, our study provides the first reports of certain parameters, such as PDL, PDW, PAL and PA, for the goat's thoracolumbar spine.

It is interesting to highlight that the pedicle width was thicker in the lumbar region than in the thoracic region. It is known that the widest pedicles allow thicker screws to be inserted, thus providing better stability and avoiding implant failure, as seen in the studies performed by Zhang *et al.* and Braun *et al.* (5,27). In our study, PAL was longer in the lumbar vertebrae than in the thoracic vertebrae. Longer pedicles allow longer screw insertion in the lumbar vertebrae and could provide better stability.

Variation of pedicle angle has been evaluated. These data correspond to the "optimum" insertion angle, which means that the insertion angle can vary around this "optimal" value by four degrees without incurring a major risk. We can therefore simplify the results by estimating insertion angles of approximately 30 ° for the T2-T3 segments, 25 ° for the T4-T5 segments, 23 ° for the T6-T11 segments, 20 ° for the T12-T13 segments, 22 ° for the L1-L3 segments, 24° for the L4 segment and 30° for the L5-L6 segments.

Jahng *et al.* reported a significant difference between the insertion angle of the thoracic region and the lumbar region in a study performed in sheep; those findings correlate with the results obtained in the current study (10). This significant difference between the lumbar and thoracic spine could be secondary to the type of vertebra (thoracic type I/ lumbar type II).

246 CT scan is the gold standard for the evaluation of the spine bony structures as seen in the 247 current study. The quality of the perceived image depends on the calibration of the imaging 248 parameters, the reconstruction algorithm of the reformatting parameters and the display mode (24). 249 Dorsal recumbency is the position of choice for spinal computed tomography evaluation. This position 250 reduces motion artifacts resulting from respiratory movements occurring during image acquisition 251 (24). In the current study, goats were placed in sternal decubitus because it is the natural position of 252 the spine and can mimic the same abnormalities, especially kyphosis in the lumbar spine. Goats were 253 also euthanized before the study and CT scan; thus, breathing did not influence the image quality.

254 There are several limitations of our study. First, a data limitation is noted due to the limited 255 number of available goat spines. To overcome this problem, the significance of the analysis was set 256 using a low p value (P<0.05); in addition, each goat has 19 thoracolumbar vertebrae, ultimately 257 constituting a sample size of 198 thoracolumbar vertebrae. However, the animals were of the same 258 age, weight, sex and breed. Furthermore, the measurements obtained in this study had a small variance 259 around the mean, indicating that a larger sample was not necessary. In addition, a comparable sample 260 number has been used in similar studies (13-14). Second, the positioning of goats, particularly 261 regarding the alignment of the spine in a single plane, can lead to measurement errors of the segment's 262 length; however, we did not measure the length of the segments. Third, this study is not a direct 263 anatomic study. Measurements were performed on CT scans, which may lead to some approximation

in the measurements. This technique was selected because CT is a noninvasive imaging modality and is a well-accepted method to assess spinal and vertebral morphometry in vivo. CT has been widely used in both humans and animal models (2,21,25). The CT scan parameters (i.e., slice thickness, pitch, and window width) used in this study follow the recommendations for orthopedics studies and are consistent with published spinal CT imaging protocols. The validation of the results obtained would have required an anatomical comparison. Since goats were sacrificed for further studies, it was unfortunately not possible to make this comparison.

271

272 Conclusion

In conclusion, this study provides a quantitative database of pedicle screw implantation corridors and morphometric dimensions of the normal thoracolumbar goat spine. These results should be considered when using pedicle screws on goat spines in experimental studies (i.e., when testing new implants or surgical techniques) to provide correct and safer screw positions. Thus, these results may limit postoperative complications and thereby limit the use of live animals.

278

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- 373
- 374 Tables
- 375 *Table 1.* Means and standard deviations of the coefficient of variation (CV) values of the
 376 thoracolumbar spine measurements of the three goats.
- 377 DT= Disc Thickness, VBW= Vertebral body width, VBD= Vertebral Body Depth, VBHd= Vertebral
- 378 Body Height dorsal, VBHv= Vertebral Body Height ventral, SCW= Spinal Canal Width, SCD= Spinal
- 379 Canal Length, TPL= Transverse Process Length, PDL= Pedicle Length, PDW= Pedicle Width, PA=
- **380** *Pedicle Angle, PAL = Pedicle Axis Length.*

Dimension	Mean CV %
VBHd	0.3686±0.273
VBHv	0.5734±0.393
DT	1.7505±0.852
VBW	0.8735±0.312
VBD	0.9694±0.558
SCW	0.7073±0.755
SCD	1.4508±1.076
TPL	0.3319±0.25
PDL	0.5324±0.211
PDW	1.1618±0.999
PAL	2.46 ±0.7204

PA	0.326±0.173

- 383 Table 2. Means and standard deviations of the CT measurement dimensions related to intervertebral
- *disc and vertebral bodies of 11 healthy goat thoracolumbar spines.*
- 385 DT= Disc Thickness, VBW= Vertebral Body Width, VBD= Vertebral Body Depth, VBHd= Vertebral
- *Body Height dorsal, VBHv= Vertebral Body Height ventral.*

	Transverse view		Sagittal view		
Vertebrae	VBW (mm)	VBD (mm)	DT (mm)	VBHd (mm)	VBHv (mm)
T2	18.37±2.7	12.10±0.4	2.83±0.4	20.71±0.7	20.55±0.7
Т3	16.76±1.5	12.30±0.8	2.19±0.2	21.33±0.8	22.45±3.2
T4	15.17±2.0	12.16±0.6	1.93±0.2	21.12±1.2	21.77±0.9
T5	13.78±1.2	12.09±0.8	2.00±0.4	21.14±0.9	21.38±0.8
T6	13.71±1.0	11.84±0.9	1.77±0.2	20.90±0.9	20.78±0.9
T7	13.41±0.9	12.39±0.6	1.71±0.2	20.87±0.8	20.99±1.0
T8	13.12±0.8	12.24±0.5	1.79±0.2	21.85±1.4	21.65±1.0
Т9	13.14±1.0	12.19±0.7	1.76±0.3	23.00±1.1	22.40±1.2
T10	13.41±1.4	11.66±0.6	1.74±0.4	24.06±1.3	23.22±1.3
T11	13.96±1.2	12.00±1.0	1.77±0.2	25.48±1.5	24.49±1.2
T12	14.36±1.2	12.03±0.8	1.90±0.2	27.79±1.2	25.15±1.8
T13	14.58±1.9	12.70±0.7	1.99±0.4	29.83±1.7	28.63±1.3
L1	15.43±1.5	12.96±0.5	2.67±0.6	33.01±1.3	31.15±1.3
L2	15.25±1.1	13.21±0.9	2.89±0.7	34.26±1.4	32.25±1.4
L3	14.75±1.4	12.63±0.9	2.84±0.7	34.69±1.2	32.26±1.2
L4	15.08±1.2	12.17±0.8	2.73±0.5	34.94±1.3	33.25±1.3
L5	17.16±1.5	11.66±0.7	2.91±0.6	34.52±1.8	32.01±2.1
L6	18.71±2.4	11.40±0.8	3.32±0.8	29.63±2.1	26.67±1.8

- 389 Table 3. Means and standard deviations of the CT measurement dimensions related to the spinal
- *canal and transverse processes of 11 healthy goat thoracolumbar spines.*

	SCW (mm)	SCD (mm)	TPL (mm)
T2	12.60±1.4	9.57±0.2	42.69±3.0
T3	12.13±1.0	9.38±0.3	42.56±2.5
T4	11.02±12	9.16±0.6	40.77±2.4
T5	10.25±0.5	8.53±0.6	41.22±1.8
T6	9.53±0.4	8.34±0.5	38.97±1.7
T7	9.27±0.4	8.20±0.4	38.38±2.4
T8	9.07±0.4	7.94±0.4	39.53±2.2
T9	9.13±0.3	8.12±0.3	40.24±2.3
T10	9.19±0.5	7.84±1.0	40.21±2.0
T11	9.26±0.4	8.12±0.4	39.67±2.8
T12	10.07±0.5	8.70±0.7	42.03±3.2
T13	9.88±0.4	8.38±0.6	45.64±2.3
L1	10.24±0.4	8.81±0.7	92.63±8.1
L2	10.63±0.3	9.01±0.6	101.86±5.7
L3	11.25±0.4	9.38±0.8	105.48±6.9
L4	12.12±0.8	10.06±0.8	108±8.6
L5	14.35±1.2	11.14±0.8	108.65±8.7
L6	16.68±0.7	10.53±0.9	89.53±7.8

SCW= Spinal Canal Width, SCD= Spinal Canal Depth, TPL= Transverse Process Length.

Table 4. Means and standard deviations of the CT measurement dimensions and angles related to the

- *pedicles of 11 healthy goat thoracolumbar spines.*
- 396 PDL= Pedicle Length, PDW= Pedicle Width, PA= Pedicle Angle, PAL = Pedicle Axis Length

	PDL (mm)	PDW (mm)	PA (°)	PAL (mm)
T2	9.54±0.6	6.04±0.4	30.334±0.62	24.3±1.5

Т3	9.44±0.3	5.87±0.3	30.457±0.55	25.3±1.5
T4	9.60±0.3	5.38±0.2	26.359±0.77	26.2±1.4
T5	10.30±1.0	5.18±0.4	24.465±0.45	26.8±1.3
T6	9.82±0.7	4.88±0.4	23.214±0.46	27.2±1.3
T7	9.72±0.8	4.97±0.4	22.663±0.63	27.2±1.2
T8	9.24±0.7	4.91±0.3	23.059±0.73	26.3±1.1
Т9	8.84±0.4	5.07±0.4	22.944±0.58	25.2±1.0
T10	8.52±1.0	5.23±0.4	23.388±0.50	24.8±0,9
T11	8.43±1.0	5.61±0.5	23.957±0.80	24.3±1.3
T12	10.56±0.5	4.77±0.6	20.960±0.51	25.1±1.7
T13	11.11±0.5	4.49±0.3	20.050±0.49	27.7±1.3
L1	12.06±1.4	5.20±0.5	21.771±0.83	29.1±1.1
L2	12.24±1.5	6.24±0.8	22.596±0.91	30.6±1.1
L3	12.28±1.0	6.28±0.4	23.035±0.91	31.6±1.4
L4	12.14±0.9	6.39±0.5	24.061±1.12	31.6±2.3
L5	12.08±1.6	6.66±0.8	29.519±0.49	31.6±2.1
L6	11.37±1.2	8.10±1.0	33.440±1.23	32.5±2.2

Table 5. Means and standard deviations of the CT measurement dimensions and angles related to the

pedicles of 11 healthy goat thoracolumbar spines.

	MEAN			
Dimension (mm)	Lumbar	Thoracic		
VBHd	33.51 ±2.5	23.39 ±3.2		
VBHv	31.27 ±2.6	22.91 ±2.6		
DT	2.89 ±0.7	1.90 ±0.4		
VBW	16.06± 2.3	14.22 ±1.9		
VBD	12.34 ±1.0	12.14 ±0.8		
SCW	12.54 ±2.4	9.92 ±1.2		
SCD	9.82 ±1.1	8.44 ±0.7		
TPL	101.03 ±10.7	40.86 ±3.1		
PDL	12.03 ±1.3	9.60 ±1.1		
PDW	6.48 ±1.1	5.13 ±0.5		
РА	25.737 ±4.37	23.796 ±2.76		

	PAL	25.9 ±1.0	31.2 ±1.0	1
399				

401 Figure legends

402

403 Figure 1. Transverse CT images obtained at the cranial aspect of L4 of a goat illustrating the
404 measurements obtained for T2 through L6. Left is right. The measurements of interest obtained for
405 each of the thoracolumbar vertebrae are vertebral body width (VBW), vertebral body depth (VBD),
406 spinal canal width (SCW), spinal canal depth (SCD) and transverse process length (TPL).

407 Figure 2. Sagittal CT images with measurements at T10 in a goat illustrating the vertebral body

408 *height at the dorsal border (VBHd), at the ventral border (VBHv) and disc thickness (DT). Cranial is*409 *to the left.*

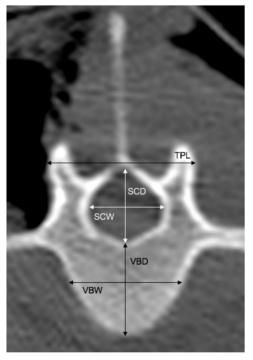
410 Figure 3. Sagittal CT images with measurements at T10 in a goat illustrating the vertebral body
411 height at the dorsal border (VBHd), at the ventral border (VBHv) and disc thickness (DT). Cranial is
412 to the left.

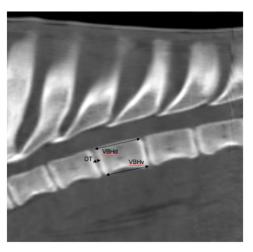
413 Figure 4. Transverse CT images obtained at the cranial aspect of L4 of a goat. Left is right. The 414 measurements of interest obtained were pedicle length (PDL), referring to pedicle type II (lumbar 415 vertebrae); pedicle width (PDW); pedicle axis length (PAL); pedicle axis angle (PAA); and sagittal 416 midline (ML) for each vertebra.

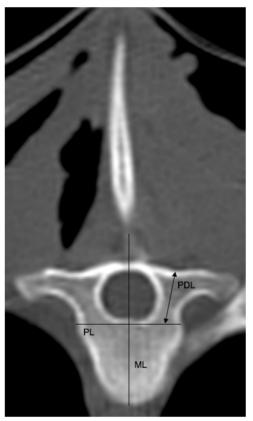
417 *Figure 5.* Variation of the ventral body width (VBW) and ventral body depth (VBD) (mean values).

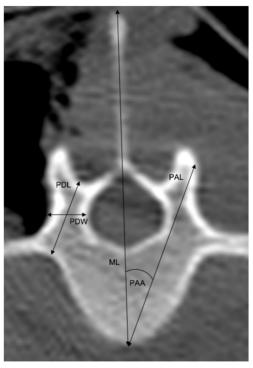
418 *Figure 6.* Variation of the ventral body height dorsal (VBHd) and ventral body heigh ventral (VBHv)
419 (mean values).

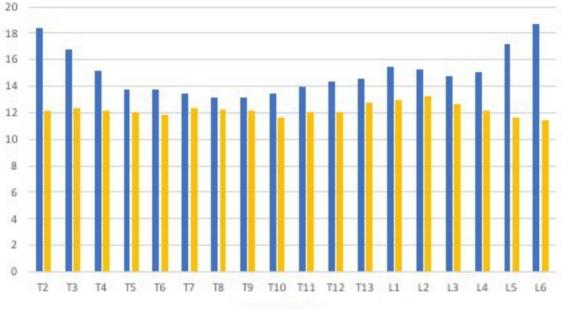
- 420 *Figure 7.* Variation of the spinal canal width (SCW) and spinal canal depth (SCD) (mean values).
- 421 Figure 8. Variation of the pedicle length (PDL), pedicle axis length (PAL) and pedicle angle (PA)
 422 (mean values).



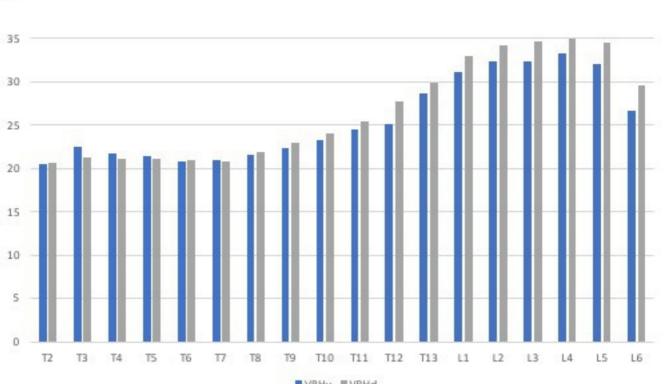




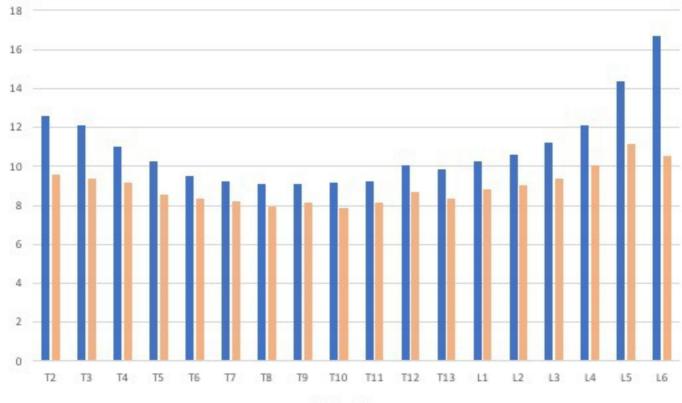




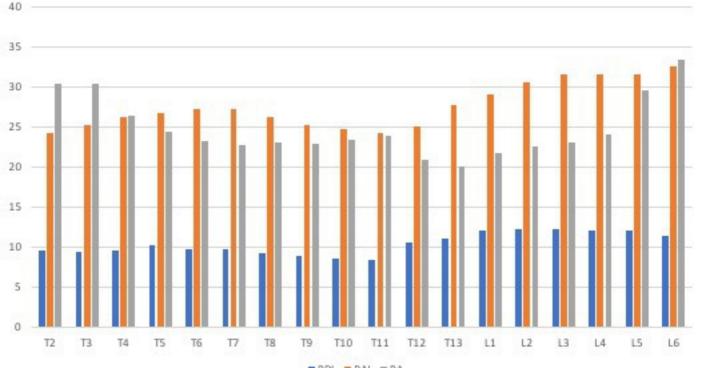
VBW VBD



■VBHy ■VBHd



SCW SCD



PDL PAL PA