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Research article

RADIOLOGICAL INVESTIGATION OF GUINEA PIG (*CAVIA PORCELLUS*) LUMBAR VERTEBRAL MORPHOLOGY – A BIOMECHANICAL ASPECT

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Numerous studies are based on the use of animal models; however, in bipedal and tetrapedal organisms there are significant differences in the biomechanics of the spinal column, which can significantly impair the quality and applicability of the results obtained. The aim of this study is to obtain basic data on the morphometric parameters of guinea pig lumbar vertebrae, the analysis of which will indicate the location of the biggest mechanical load. The lumbar vertebra morphometry test was performed by means of X-ray imageing obtained from 12 guinea pigs, with equal numbers of males and females. The results of investigations show that guinea pig lumbar vertebrae have an irregular trapezoid geometry and that the measured body lengths of L4 and L5 are the largest. The height parameters determined in the medial level showed that L4 had the most concave body. Moreover, L4 had the greatest depth of the spinal canal at the same measurement level. Consequently, in guinea pigs, the greatest load is in the L4 region, unlike in humans, where, due to the axial load of the spinal column, the highest pressure is exerted on the last lumbar vertebrae.

Keywords: biomechanics, guinea pig, lumbar spine, morphometry, radiology

INTRODUCTION

Knowledge of biomechanics enables a better understanding of the role of bones and associated soft tissues in stabilizing the spine, as well as an understanding of the destabilizing effects that can occur due to the appearance of tumors, traumatic and degenerative damages [1]. In a functional sense, bone and soft tissue structures are closely connected and their mutual action achieves the stability of the spine and its mobility in all three axes [2].

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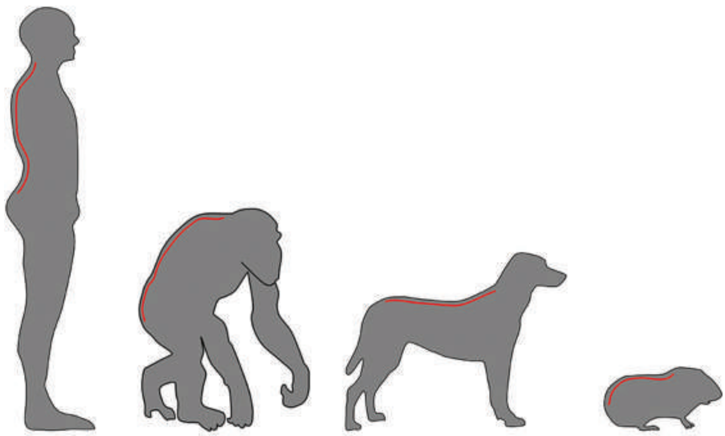
In humans, who are bipedal organisms, the thoracic part of the spine has limited mobility because ribs are attached to the vertebrae at one end and to the sternum at the other end. Unlike the thoracic segment, the mobility of the lumbar spine is significantly higher and at the same time, it bears the greatest axial load [2]. It is known that bones adapt to the action of mechanical forces by changing their morphology [3], so the size of the thoracic vertebrae in humans increases from the first to the last [1], and this trend continues distally so that the last lumbar vertebra has the greatest length, height and width [4].

Considering the high incidence of various pathological conditions in the spinal column of humans, which predominantly affect the lumbar region, numerous studies are aimed at finding an adequate biomechanical model to examine the static-mechanical relationships of lumbar vertebrae. In the available literature, there are various findings of different morphometric and/or biomechanics examinations of the spinal column performed on rabbits [5], dogs [6], pigs [7], sheep [8] and cattle [9,10]; however, the search for an optimal animal model is still ongoing. It should be borne in mind that there are significant differences in the biomechanics of the spinal columns of bipedal and tetrapedal organisms (Supplementary Figure S1), which can significantly impair the quality and applicability of the results obtained.



Supplementary **Figure S1:** Presentation of the morphometry of the spinal column in different species of mammals.

Guinea pigs *(Cavia porcellus)* are a herbivorous species of rodents from the family Caviidae which due to their low body weight, short reproductive cycle, calm temperament, as well as anatomical and physiological characteristics, are increasingly used as models in various studies [11]. In neurology and orthopedics, guinea pigs have been used to examine ischemic lesions in the spinal cord [12], and also for the study of spontaneous and induced osteoarthritis [13]. The spinal column of rodents has a total of 26 presacral vertebrae, composed of 7 cervical and 19 thoracolumbar vertebrae [14]. The cervical spine region of mammals is characterized by the smallest variations in the number of vertebrae, which is usually attributed to the pleiotropic function of Hox genes. In addition, variations in the number of cervical vertebrae are associated with an increased risk of prenatal mortality and neonatal cancer [14,15]. On the other side, the thoracolumbar region of the spine of guinea pigs shows greater variability, and in most individuals, it is composed of 13 thoracic and 6 lumbar vertebrae [16].

The aim of this study was to obtain data on the morphometric parameters of the lumbar vertebrae of guinea pigs and to view them from the aspect of biomechanics in order to obtain information on the mechanical load on the lumbar spine of these animals.

MATERIAL AND METHODS

Animals

The examination was performed on 12 guinea pigs *(Cavia porcellus)*, with an equal number of males (6) and females (6), body weight 380-800 g. All morphometric examinations of the lumbar vertebrae were performed on X-rays (permission no. 323-07-0850112019-05 issued by the Veterinary Administration of the Ministry of Agriculture and Environmental Protection of the Republic of Serbia). Experimental procedures were performed in compliance with Directive 2010/63/EU on the protection of animals used for experimental and other scientific purposes.

Preparation for radiological examination

In order to minimize the guinea pigs' movements and to obtain images of optimal quality for analysis, all animals were anesthetized following a three-hour deprivation of food and water. Animals were anesthetized using ketamine hydrochloride (Ketamidor 10%, Richter Pharma, Austria) in a dose of 60 mg/kg body weight, with xylazine hydrochloride premedication (Xylased, Bioveta, Czech Republic) in a dose of 4 mg/kg. The application was performed subcutaneously, using a 25 G-diameter injection needle.

Radiological examination

All radiographs were performed using a ZooMax Gold X-ray machine (Control-X Medical, Hungary). The animals were placed in a plexiglass basket, and morphometric examinations of various parameters of the lumbar vertebrae were performed only on images made in lateral recumbency in the laterolateral projection (Figure 1A) because in the ventrodorsal projection it was not possible to accurately measure the width of the vertebral body due to summation of shadows of gastrointestinal contents and bony outlines of vertebrae. The X-rays were performed at a focus film distance of 90 cm, using a voltage of 44 kVp, while the exposure was 5 mAs.

Morphometric examinations of lumbar vertebrae

Morphometric examinations of all six lumbar vertebrae (L1-6) of guinea pigs were performed in the RadiAnt DICOM Viewer program by three examiners. The length of vertebral bodies was measured at three different levels: dorsal (L_D), medial (L_M) and ventral (L_V), as well as the height: cranial (H_{CR}), medial (H_M) and caudal (H_{CA}). The depth of the spinal canal was measured in the central part of each examined vertebra (Figure 1B-D).

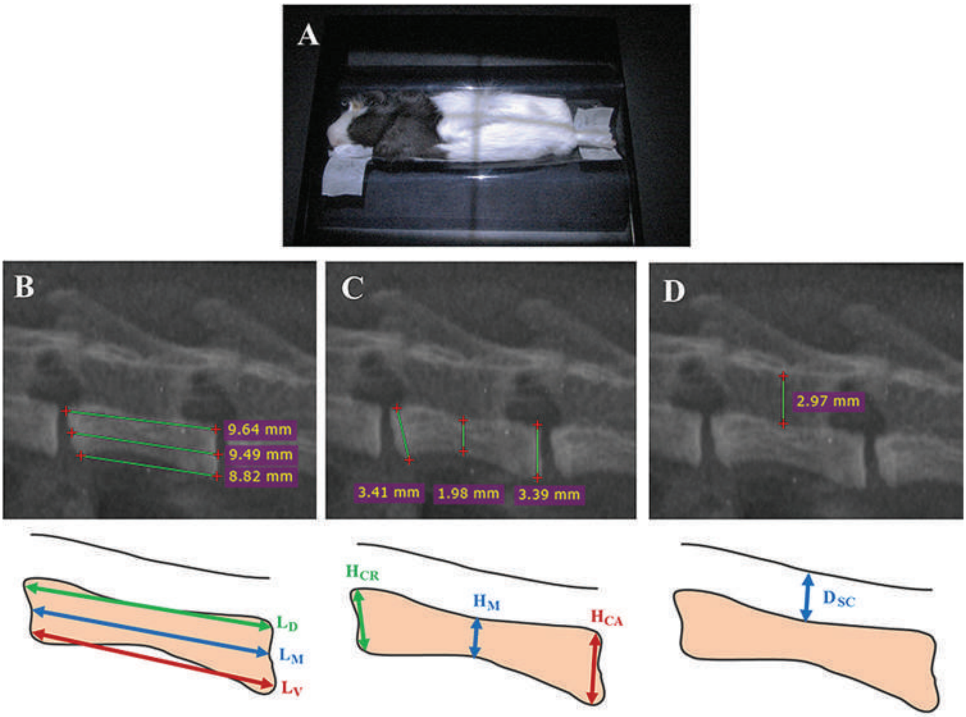


Figure 1. Lateral recumbency of guinea pig in a plexiglass basket **(A)** and morphometric examinations of lumbar vertebrae: **(B)** measuring the length in the dorsal (LD), medial (LM) and ventral (LV) parts of the vertebral body; **(C)** measuring height in the cranial (HCR), medial (HM) and caudal (HCA) parts of the body; **(D)** measuring the depth of the spinal canal (DSC).

Data analysis and statistical procedures

Morphometric parameters of lumbar vertebrae (length and height of vertebral bodies at three different levels and depth of the spinal canal) are presented as mean ± standard deviation (SD) in millimeters. All individual values are presented in the Supplementary Material. The sample size (n) was 12. Differences in the length and height of vertebrae bodies in all three levels were tested by factorial analysis of variance (two-way ANOVA) with the number of vertebrae and the level of measurement as factors, and *post hoc* compared by Tukey's honest significant difference (HSD) test. Differences in depth of the spinal canal were tested by single factor analysis of variance (one-way ANOVA) and *post hoc* compared by Tukey's HSD test. Correlations between body weight and the morphometric parameters of lumbar vertebrae were examined using Pearson's correlation coefficient as well as linear regression of morphometric parameters as the dependent variable on body weight as the independent variable. Deviations in linear regression curve slopes from zero were tested by the F-test. Comparisons of linear regression curve slopes were also performed using the F-test. Statistical significance of the correlation coefficient was tested using Student's t-test. The significance level was 0.05. All analyses were conducted using GraphPad Prism 8 (GraphPad Software Inc.).

RESULTS

Length of lumbar vertebral bodies

Two-way ANOVA showed a significant difference in the lengths of different lumbar vertebrae ($F=15.4$; $p<0.0001$) as well as a significant difference between the different levels of measurement, namely dorsal (L_D), medial (L_M) and ventral (L_V) ($F=8.754$; $p<0.001$) (Figure 2A, Supplementary Tables S1 and S2).

Supplementary table S1: Length of lumbar vertebral bodies (in millimeters); L_D – length in the dorsal level; L_M – length in the medial level; L_V – length in the ventral level.

						L_D						
L1	6.567	6.870	6.903	7.380	7.320	7.133	8.260	9.177	8.070	8.527	9.133	8.320
L2	7.160	7.390	7.460	8.170	8.000	7.843	8.980	10.167	8.823	9.383	9.870	8.963
L3	7.557	7.927	7.963	8.737	8.420	8.417	9.573	10.733	9.400	10.100	10.567	9.557
L4	8.047	8.263	8.293	9.217	8.893	8.893	10.000	11.233	9.960	10.633	11.000	9.990
L5	7.797	8.073	8.220	9.303	8.670	9.403	9.700	11.233	10.100	11.133	11.100	9.777
L6	6.787	7.067	7.073	8.230	7.767	8.840	8.387	10.097	8.863	10.667	10.153	8.480
						L_M						
L1	6.317	6.417	6.450	6.857	7.320	6.690	7.743	8.830	7.560	8.167	8.847	7.657
L2	6.820	6.977	7.137	7.777	7.820	7.507	8.517	9.643	8.473	9.023	9.600	8.540
L3	7.437	7.627	7.617	8.253	8.097	8.173	9.120	10.233	9.020	9.710	10.247	9.023
L4	7.780	7.993	8.103	8.897	8.793	8.573	9.620	10.833	9.577	10.267	10.733	9.507
L5	7.690	7.863	8.003	9.170	8.590	9.117	9.497	10.967	9.803	10.933	10.900	9.423
L6	6.797	7.000	7.020	8.263	7.720	8.630	8.407	10.100	8.670	10.233	9.947	8.273
						L_V						
L1	5.597	6.003	5.943	6.537	6.457	6.247	7.587	8.560	7.097	7.913	8.573	7.337
L2	6.357	6.483	6.693	7.477	7.090	6.650	8.350	9.210	7.900	8.473	9.143	8.017
L3	7.170	7.440	7.263	8.067	7.563	7.427	8.883	9.743	8.830	8.903	9.897	8.833
L4	7.393	7.810	7.797	8.457	8.010	8.003	9.173	10.367	9.400	10.067	10.600	9.267
L5	7.373	7.397	7.390	8.590	7.917	8.690	8.783	10.300	9.180	10.467	10.600	9.133
L6	6.060	6.507	6.610	7.450	7.087	8.087	7.883	9.600	7.890	9.757	9.587	7.973

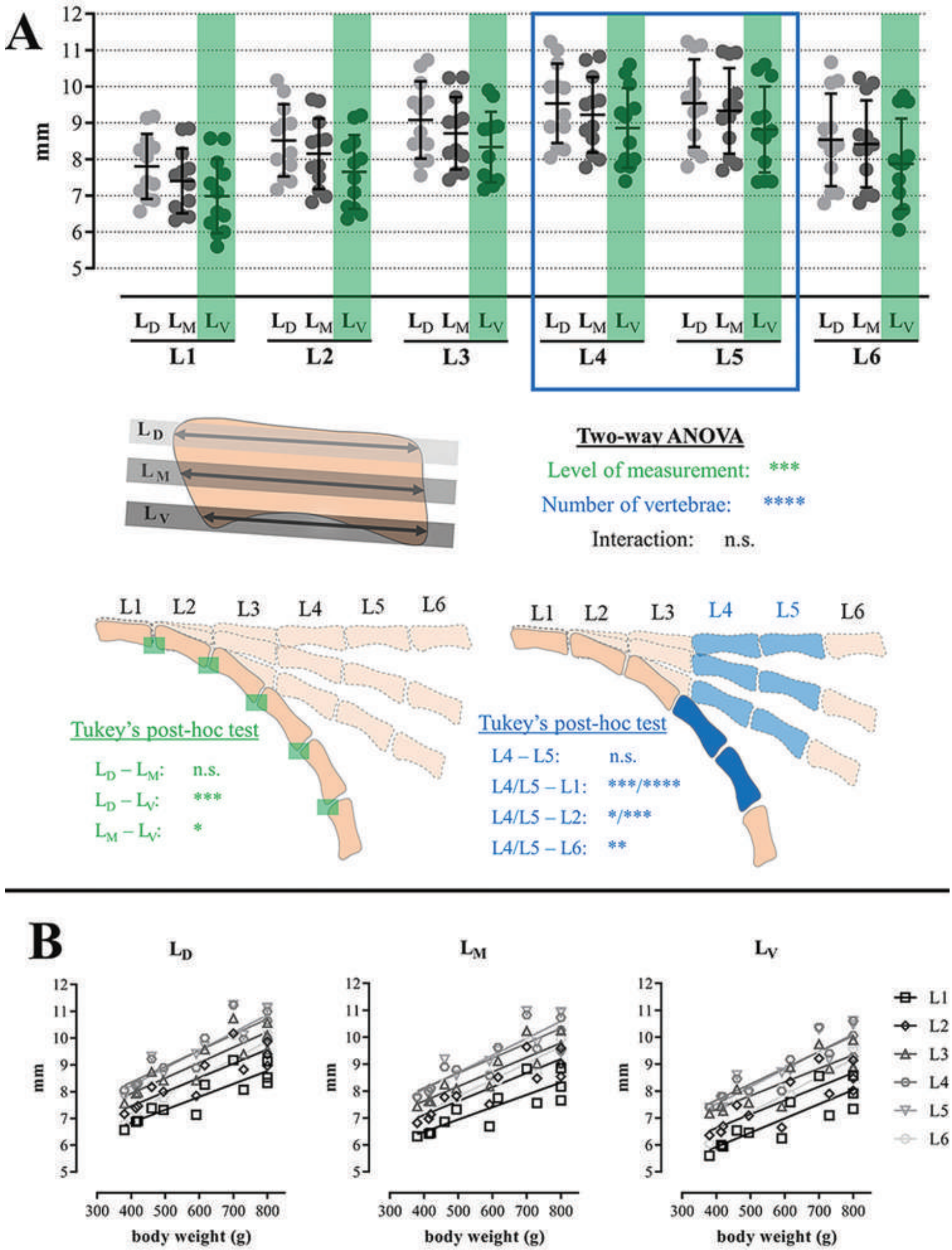


Figure 2. (A) Length of guinea pig lumbar vertebrae bodies in dorsal, medial and ventral levels. **(B)** Linear regression of lumbar vertebrae bodies lengths as the dependent variable on body weight as the independent variable. LD – length in the dorsal part of the vertebral body; LM – length in the medial part of the vertebral body; LV – length in the ventral part of the vertebral body; p<0.05; ** p<0.01; *** p<0.001; **** p<0.0001; n.s. – nonsignificant.

Supplementary table S2: Height of lumbar vertebral bodies (in millimeters); H_{CR} – height in the level of cranial epiphysis; H_M – height in the medial level; H_{CA} – height in the level of caudal epiphysis.

						H_{CR}						
L1	3.003	2.950	2.977	2.573	2.833	3.473	3.483	3.100	3.643	2.973	3.023	3.583
L2	2.887	3.003	2.945	2.750	2.899	3.327	3.307	3.400	3.697	3.173	2.930	3.500
L3	2.910	3.257	3.083	2.933	3.091	3.400	3.520	3.240	3.917	3.210	3.143	3.773
L4	3.433	3.210	3.322	2.933	3.155	3.653	3.700	3.477	4.167	3.337	2.837	3.793
L5	3.390	3.183	3.287	3.170	3.213	3.630	3.683	3.613	4.307	3.280	3.287	3.703
L6	3.613	3.513	3.563	3.243	3.440	3.683	3.930	3.810	4.253	3.250	3.240	3.710
						H_M						
L1	2.423	2.467	2.445	2.393	2.435	2.803	2.923	2.550	3.233	2.233	2.480	2.683
L2	2.560	2.220	2.390	2.347	2.319	3.043	3.163	3.010	3.210	2.413	2.750	2.820
L3	2.377	2.177	2.277	2.370	2.274	2.683	3.010	2.617	3.340	2.400	2.467	2.830
L4	2.410	1.983	2.197	2.017	2.066	2.963	2.517	2.367	3.270	2.220	2.310	2.567
L5	2.567	2.400	2.483	2.267	2.383	2.593	2.797	2.677	3.353	2.430	2.400	2.850
L6	2.523	2.287	2.405	2.550	2.414	2.823	2.790	2.800	3.390	2.580	2.617	2.810
						H_{CA}						
L1	3.133	3.167	3.150	2.737	3.018	3.540	3.693	3.743	3.927	3.090	3.070	3.583
L2	3.237	3.210	3.223	2.847	3.093	3.513	3.603	3.743	4.140	3.307	3.303	3.710
L3	3.257	3.343	3.300	3.153	3.266	3.597	3.807	3.280	4.133	3.477	3.527	3.803
L4	3.373	3.433	3.403	3.200	3.346	3.877	3.947	3.823	4.487	3.110	3.500	4.000
L5	3.480	3.880	3.680	3.610	3.723	3.937	4.193	4.027	4.603	3.603	3.863	4.373
L6	3.603	3.920	3.762	3.620	3.767	3.967	4.120	4.050	4.513	3.990	3.860	4.147

Interaction between these two factors was insignificant ($F=0.042$; $p>0.9999$) since there was a same trend of L_D, L_M and L_V in all lumbar vertebrae. Namely, L_V was the smallest while L_D was the largest in all vertebrae. The bodies of the L4 and L5 vertebrae had the greatest length, thus Tukey's HSD test (main effect of the number of vertebrae) showed significant differences in the lengths of both L4 and L5 compared to those of L1, L2 and L6. The body of L1 had the smallest length and in addition to L4 and L5, it differed significantly from L3 (Figure 2A). Tukey's HSD test (main effect of the level of measurement) also showed that both dorsal length (L_D) and medial length (L_M) were significantly different, i.e. greater compared to the ventral length (L_V), with no significant differences between L_D and L_M, although L_D had the greatest mean value. Pearson's correlation coefficient showed a significant positive correlation between the guinea pigs' body weight and the lengths of all lumbar vertebrae in all three levels of measurement (Table 1A). The average correlation coefficient was 0.870. This relationship between the length of lumbar vertebrae and body weight was confirmed by regression analysis. The slopes of all regression lines (for all vertebrae in every level of measurement) were significantly different from zero, while there was no significant difference between the slopes of the different lines (Figure 2B, Supplementary Table S2).

Table 1. Pearson's correlation coefficient (r) of the body weight and morphometric parameters of lumbar vertebrae.

		L1	L2	L3	L4	L5	L6
A) length of vertebrae body	L_D	0.882 ***	0.869 ***	0.882 ***	0.887 ***	0.897 ****	0.864 ***
	L_M	0.839 ***	0.877 ***	0.884 ***	0.871 ***	0.879 ***	0.842 ***
	L_V	0.852 ***	0.824 ***	0.851 ***	0.890 ***	0.901 ****	0.865 ***
B) height of vertebrae body	H_{CR}	0.506 n.s.	0.631 *	0.584 *	0.292 n.s.	0.456 n.s.	0.141 n.s.
	H_M	0.277 n.s.	0.536 n.s.	0.541 n.s.	0.414 n.s.	0.415 n.s.	0.580 *
	H_{CA}	0.455 n.s.	0.592 *	0.603 *	0.418 n.s.	0.547 n.s.	0.653 *
C) depth of spinal canal	D	0.797 **	0.809 **	0.746 **	0.672 *	0.735 **	0.594 *

Length of guinea pig lumbar vertebrae bodies (L1 to L6) at the dorsal (LD), medial (LM) and ventral (LV) levels; height of guinea pig lumbar vertebrae bodies at the cranial (HCR), medial (HM) and caudal (HCA) levels; depth (D) of the spinal canal of lumbar vertebrae. ****p<0.0001; ***p<0.001; **p<0.01; *p<0.05; n.s. – nonsignificant.

Height of lumbar vertebral bodies

Two-way ANOVA showed a significant difference in the heights of different lumbar vertebrae (F=7.593; p<0.0001), a significant difference between the different levels of measurement, namely cranial (H_{CR}), medial (H_M) and caudal (H_{CA}) (F=189.7; p<0.0001), as well as a significant interaction between these two factors (F=2.439; p<0.01) (Figure 3A, Supplementary Tables S1 and S3). L5 and L6 had the greatest height. Tukey's HSD test (main effect of the number of vertebrae) showed a significant difference in the heights of both L5 and L6 compared to L1 and L2, while that of L6 was significantly higher compared to L3 and L4 as well. Tukey's HSD test (main effect of the level of measurement) showed significant differences between all three levels of measurement, with H_{CA} being the greatest and H_M the smallest. Additionally, height at the level of both cranial and caudal epiphyses showed a trend of increase from L1 to L6. Namely, at the level of the cranial epiphysis, the *post-hoc* test showed that L6 was significantly greater compared to both L1 and L2, while height at the level of the caudal epiphysis was significantly greater in L5 and L6 compared to L1, L2 and L3 (Figure 3A). On the other hand, there was neither trend nor any significant difference at the medial level. L4 had the smallest average H_M, which is consistent with the significant two-way ANOVA interaction. In addition, L4 had the greatest difference between H_{CR} and H_M, and together with L6 the greatest difference between H_{CA} and H_M (Figure 3A). Unlike lumbar vertebral length, height was not as strongly correlated with body mass/weight

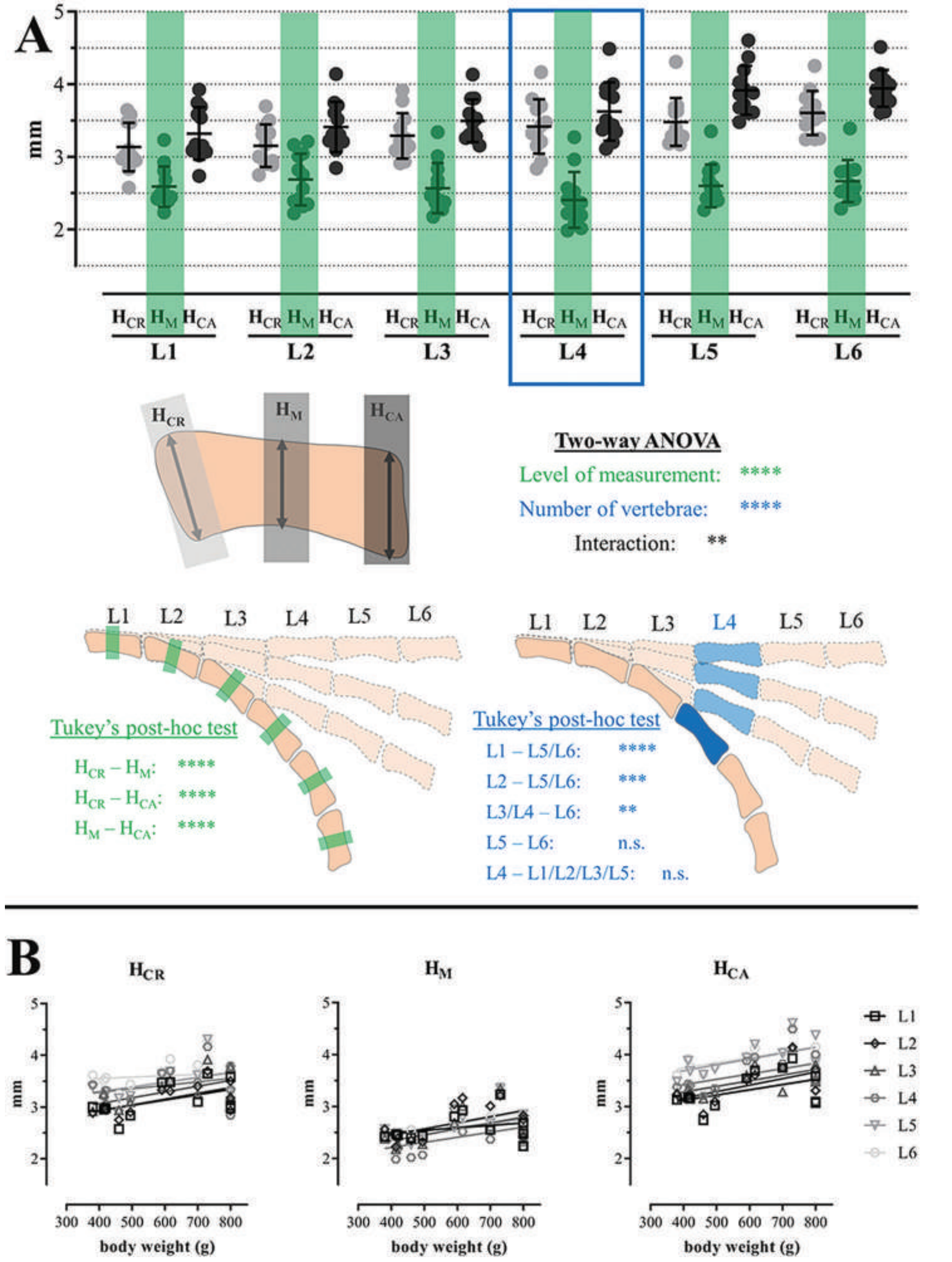


Figure 3. (A) Height of guinea pig lumbar vertebrae bodies in the cranial, medial and caudal levels. **(B)** Linear regression of lumbar vertebrae body heights as the dependent variable on body weight as the independent variable. HCR – height in the cranial part of the vertebral body; HM – height in the medial part of the vertebral body; HCA – height in the caudal part of the vertebral body; ** p<0.01; *** p<0.001; **** p<0.0001; n.s. – nonsignificant.

(Table 1B). Pearson's correlation coefficient showed a significant positive correlation between guinea pig body weight and the height of the cranial and caudal epiphyses of L2 and L3 as well as the caudal epiphysis and medial height of L6. Correlation coefficients for the listed parameters were in the range from 0.580 to 0.631, with an average correlation coefficient of only 0.480. Similarly, regression analysis (Figure 3B, Supplementary Table S3) showed that only the slopes of the regression lines for the cranial and caudal epiphyses of L2 and L3 as well as the caudal epiphysis and medial height of L6 were significantly different from zero, while there were no significant differences between the slopes of different lines.

Supplementary table S3: Depth of the spinal canal (in millimeters).

L1	2.127	2.270	2.310	2.393	2.063	2.377	2.483	2.997	2.353	2.790	3.160	2.750
L2	2.130	2.437	2.360	2.493	2.210	2.467	2.507	3.080	2.503	3.007	3.173	2.723
L3	2.433	2.667	2.547	2.603	2.490	2.683	2.680	3.283	2.533	3.180	3.500	2.937
L4	2.410	2.820	2.867	2.973	2.557	2.727	2.997	3.507	2.597	3.463	3.500	3.107
L5	2.217	2.507	2.413	2.947	2.230	3.000	2.817	3.217	2.520	3.340	3.280	2.937
L6	1.623	1.783	1.697	2.193	1.670	2.243	1.980	2.320	1.867	2.840	1.937	2.083

Depth of the spinal canal

Similar to the length of lumbar vertebrae, the depth of the spinal canal was characterized by greater variability, with the greatest depth in L4 and the smallest in L6. One-way ANOVA showed significant differences ($F=10.2$; $p<0.0001$). Tukey's HSD test showed that the depth of the spinal canal of L4 was significantly greater compared to L1 and L6. In addition, the spinal canal of L6 was significantly smaller compared to all the other lumbar vertebrae (Figure 4A, Supplementary Tables S1 and S4). Pearson's correlation coefficient showed a significant positive correlation between the guinea pigs' body weight and the depth of the spinal canal of all six lumbar vertebrae (Table 1C). The average correlation coefficient was 0.726. This relationship between depth of lumbar canal and body mass/weight was confirmed by regression analysis. The slopes of all regression lines (for all vertebrae) were significantly different from zero, while there was no significant difference between the slopes of the different lines (Figure 4B).

DISCUSSION

Regulation of bone growth is a complex process that depends on genetic factors, vascularization [17], the influence of hormones [18, 19], as well as biomechanical factors [20]. The influence of mechanical force on bone growth is often considered through Hueter-Volkmann's law, which indicates that an increase in pressure in the epiphyseal growth zones has an inhibitory effect, as opposed to distension, which promotes longitudinal bone growth [21]. In studies performed on rats, a decrease in

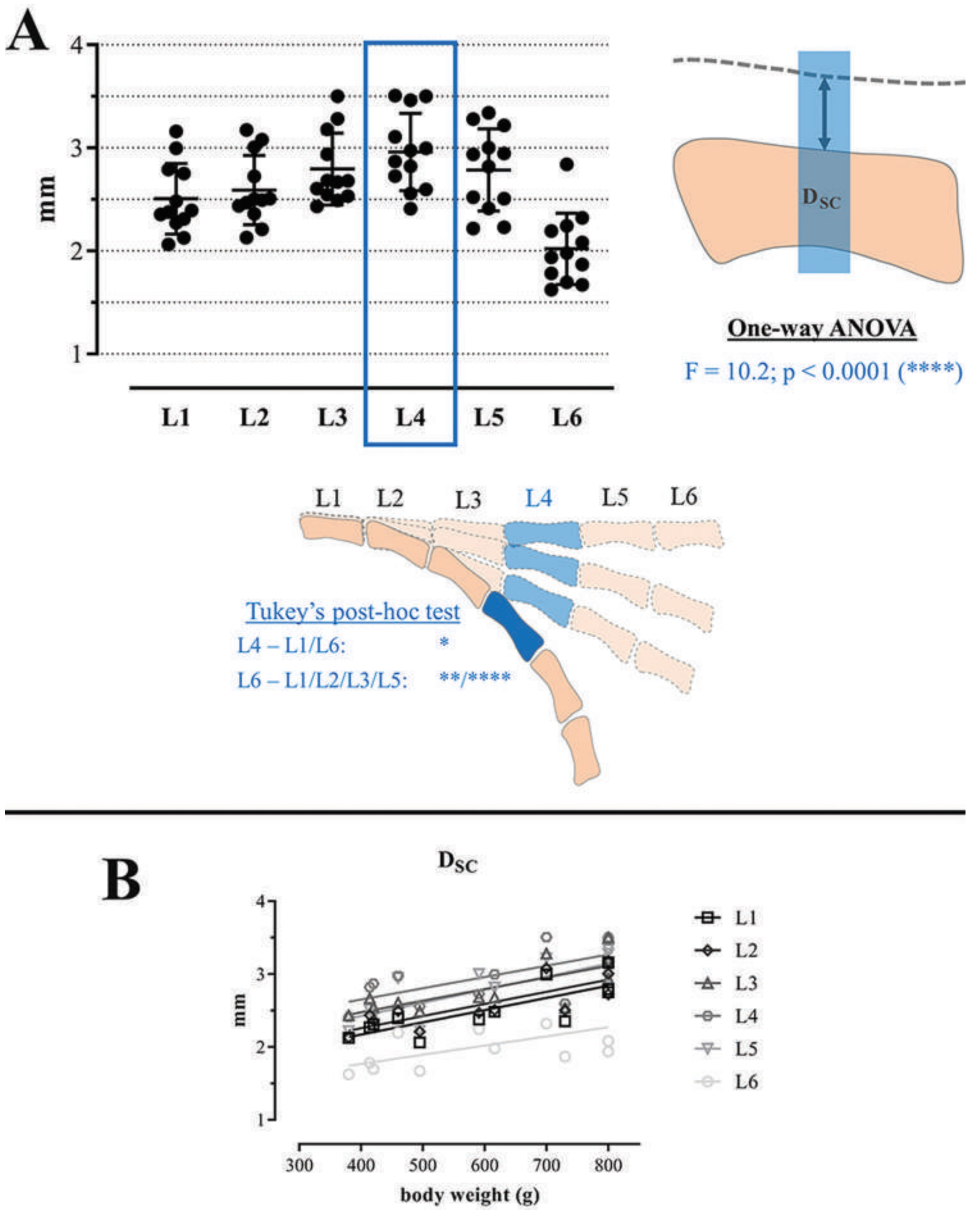


Figure 4. (A) Depth of the spinal canal of guinea pig lumbar vertebrae. **(B)** Linear regression of depth of the spinal canal of lumbar vertebrae as the dependent variable on body weight as the independent variable. DSC – depth of the spinal canal; * $p<0.05$; ** $p<0.01$; **** $p<0.0001$.

the growth of the forelimbs was observed with increased axial load [22], while the body length of the caudal vertebrae recorded an increase of 14% in distraction, i.e. a decrease of 22% in increasing axial pressure [23]. Nevertheless, the biomechanical impact on bone growth and morphology is much more complex and there are a lot of inconsistent data in the available literature [24].

Although the mechanical modulation of longitudinal bone growth by compressive forces is best known, the effects of torsion and bending on longitudinal, rotational and angular bone development should not be ignored [25]. The influence of spinal flexion on the morphology of the vertebral body was examined by [26]. They suggested that seals and dolphins have round vertebral bodies due to pronounced lateral and sagittal flexion, while in tetrapedal organisms, due to predominant sagittal flexion, the vertebral body has an irregular quadrangular shape. The results of our study showed that the body length of the lumbar vertebrae of guinea pigs differs in the dorsal, medial and ventral areas, the dorsal length being the largest and the ventral the smallest. Hueter-Volkmann's law, which describes the influence of force on bone growth, points out that during skeletal development bone growth is relatively retarded in places of increased mechanical compression and relatively accelerated in places of reduced load [27]. This may explain the irregular trapezoidal geometry of the bodies of the lumbar vertebrae of guinea pigs, which due to sagittal flexion and arched lumbar spine, exert the greatest pressure in the cranioventral and caudoventral parts of the bodies of two adjacent vertebrae, which could lead to the earlier closure of the ventral epiphyseal growth zone with unhindered development of the proximal part of the vertebral body.

The shape and size of the vertebrae, as well as their position inside the spinal column, should enable an even distribution and transfer of forces through the central part of the vertebral body. In bipedal organisms, pressure on the spinal column increases in a caudal direction, which is accompanied by a proportional increase in the dimensions of the vertebral body [28], so that the last lumbar vertebra has the greatest length, width and height [4]. Takahashi et al. also showed that in humans the greatest load is exerted in the lumbar region of the spine, and that disc protrusions are most common between L4 and L5 [29]. According to the results of our study, guinea pigs did not exhibit a proportional increase in all the examined morphometric parameters of the lumbar vertebrae in the craniocaudal direction, as occurs in humans, but the body lengths of L4 and L5 were significantly longer than those of L1, L2 and L6. On the other hand, the heights of the lumbar vertebrae generally showed an increase in the caudal direction, so that the heights of the cranial epiphyses in L1 and L2 are significantly lower than in L6, and the caudal epiphyses of L1, L2 and L3 have significantly lower values than L5 and L6. The heights measured in the central part of the body are uniform and do not show significant deviations between the vertebrae. However, they are significantly smaller in relation to the height of the cranial and caudal epiphyses, as a result of which the ventral outline of the vertebrate body of guinea pigs has a slight concavity. The concavity is the most pronounced in L4, which is characterized by the smallest medial height and the greatest difference in medial height versus the height of the cranial and caudal epiphyses.

The relationship between the length and height of the vertebral body in tetrapedal organisms is correlated with a different mechanical load on the lumbar spine and the transmission of force through the vertebral body. Therefore, differences observed in heights and the concave appearance of the ventral outline of the vertebral body in guinea pigs can be explained as an adaptive response of the bone to bending forces that can occur in these animals due to lordosis of the lumbar spine. Martin and Burr indicated that when the bone is bent, fluid is pushed through the canalicular bone system against the action of force and performs a mechanical stimulus on the cells, which ultimately results in bone adjustment to mechanical load and the appearance of curvature of the periosteal and endocortical bones [30].

The basic function of the spinal column is to provide mechanical stability and protect the spinal cord. The vertebral body, as the bearer of the greatest load, together with the vertebral arch, form the spinal canal and protect the spinal cord from injuries. However, the diameter of the spinal canal is not uniform along its entire length and in humans its width increases from the first to the last lumbar vertebra, while the depth is lowest at the L3 level and increases in a caudal direction [31]. Thus, in humans, there is a correlation between the diameter of the spinal canal and the place of greatest load on the spine, which can be considered a remarkable protective mechanism that aims to prevent pressure on the spinal cord that could occur when a higher mechanical force is applied. The results of our study show that in guinea pigs, the greatest depth of the spinal canal was measured at the level of L4, and the smallest in L6.

CONCLUSION

The results of our study indicate that in guinea pigs there is no linear increase in the values of morphometric parameters of the lumbar vertebrae in the direction from the first to the last, as is the case in humans. In guinea pigs, L4 and L5 were observed to have the greatest body lengths, while the ventral side of the body of L4 was the most concave. Additionally, the depth of the spinal canal was greatest at the level of L4. This atypical morphology of the lumbar vertebrae leads to the conclusion that the direction of force transmission through the spinal column of tetrapedal organisms differs from that in bipedal organisms, and that the center of gravity of the load is shifted in a cranial direction. Also, the atypical morphology of L4 could indicate that this vertebra has the role of "shock absorber" and that it suffers the greatest load. However, it must be remembered that this conclusion was made on the basis of vertebral body morphometry alone, while the biomechanics of the spine are influenced by numerous other factors such as bone structure (direction of provision trabeculae and density), the characteristics of facet joints, intervertebral discs and associated soft tissue structures.

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Author's contributions

MM, SK, and MLM conceived of the study, participated in its design and coordinated the work. Morphometric measurements were performed by MM, SK, and AT. NT, MM, and SK performed the statistical analysis. MM, SK, and AT wrote the manuscript in consultation with MLM and NT. All authors read and approved the final manuscript.

Declaration of conflicting of interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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RADIOLOŠKA ISPITIVANJA MORFOLOGIJE LUMBALNIH PRŠLJENOVA ZAMORACA (*CAVIA PORCELLUS*) – BIOMEHANIČKI ASPEKT

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Brojne studije su zasnovane na upotrebi animalnih modela, ipak, kod bipedalnih i tetrapedalnih organizama postoje značajne razlike u biomehanici kičmenog stuba, koje mogu značajno narušiti kvalitet i primenjivost dobijenih rezultata. Cilj ovog ispitivanja je da se dobiju osnovni podaci o morfometrijskim parametrima lumbalnih pršljenova zamoraca, čijom analizom će se ukazati na mesto najvećeg mehaničkog opterećenja. Morfometrijsko ispitivanje lumbalnih pršljenova zamoraca je sprovedeno na rendgenskim snimcima 12 jedinki, sa jednakim brojem mužjaka i ženki. Rezultati ispitivanja pokazuju da lumbalni pršljenovi zamoraca imaju nepravilnu trapezoidnu geometriju i da su izmerene dužine L4 i L5 najveće. Parametri visine određivani su u medijalnom nivou i pokazali su da L4 ima najkonkavnije telo. Štaviše, L4 je imao najveću dubinu kičmenog kanala na istom nivou merenja. Shodno tome, kod zamoraca je najveće opterećenje u L4 regiji za razliku od ljudi, gde se usled aksijalnog opterećenja kičmenog stuba najveći pritisak ostvaruje na poslednjim lumbalnim pršljenovima.