

Relation between defects in the lumbar spine and the position and dimensions of individual vertebrae in German Shepherds

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Summary

The German Shepherd is among the breeds most prone to pathologies of the lumbosacral spine. The aim of the study was to examine how the presence of spine pathology affects the shape of the lumbar spine and dimensions of individual vertebrae. Mathematical analysis consisted of three measurements for each lumbar vertebra. Based on the analysis, it was concluded that there was a correlation between the height of the first five vertebrae and the occurrence of the lumbosacral transitional vertebra (LTV). It was also shown that spondylosis manifested most often with a change in the distance between individual lumbar vertebrae. There was no correlation between the incidence of spondylosis and the height of the vertebral canal. In conclusion, the presence of a LTV significantly changes the dimensions of other vertebrae in the lumbar spine, which can lead to other pathological changes in the vertebral column.

Keywords: lumbar vertebrae, spine, dogs, German Shepherds

The German Shepherd is among the breeds with the highest risk of lumbosacral spine pathology (14, 20, 25-27, 32). The most common conditions of this region of the spine in German Shepherd dogs include spondylosis, spondyloarthrosis, transitional vertebrae, and cauda equina syndrome (CES) (12, 22). Spondylosis is a degenerative condition of the spine involving proliferative changes, particularly in the dorsal parts of vertebral bodies and the margins of cranial and caudal vertebral notches in intervertebral spaces, leading to the formation of exostoses or bridging of the vertebrae (8, 21). These abnormalities are most commonly observed in the thoracic and lumbosacral regions of the spine, and more specifically, between the second and third lumbar vertebrae (L2-L3) and between the seventh lumbar and first sacral vertebrae (L7-S1)

(19, 29). The German Shepherd, Boxer, Bohemian Shepherd, and Alaskan Malamute are breeds particularly predisposed to this condition (3, 4, 11, 21). In most dogs, spondylosis is not accompanied by clinically observable motor symptoms, though the decreased intervertebral mobility may produce non-specific signs, such as reduced activity or gait abnormalities due to the pressure of bony structures on the ventral roots of spinal nerves (6, 30). The most common clinical signs of lumbar spondylosis include spinal pain in the affected region, thoracic-lumbar stiffness, pelvic limb lameness, ataxia, and other forms of abnormal gait (17).

Another relatively common spinal pathology in the German Shepherd is spondyloarthrosis, or intervertebral joint degeneration. It results from proliferative changes related to the chronic inflammation of these

joints (2). These are typically accompanied by pain, tension, and contracture of spine extensor muscles, as well as pain in other soft structures of the back and reduced activity. German Shepherds are also often affected by transitional vertebrae, i.e. abnormal vertebrae with structural characteristics of those forming a neighboring segment of the spine. The condition may affect an entire vertebra or its part. Such transitional vertebrae are most commonly found near the lumbosacral junction. The term “lumbosacral transitional vertebrae” (LTV) refers to an abnormal vertebra located between the last normal lumbar vertebra and the first normal sacral vertebra (5, 7). Such vertebrae have a highly variable morphology with characteristics typical of both lumbar and sacral vertebrae. If the first sacral vertebra is affected and develops characteristics of a lumbar vertebra, this is referred to as S1 lumbarization. On the other hand, if the seventh lumbar vertebra is affected and resembles a sacral vertebra, this is termed sacralization (12, 18).

Based on radiographic images, a number of LTV categories have been defined. Type 1 refers to a normal sacrum, type 2 is characterized by a separation of the S1 spinous process, and types 3-5 involve more or less advanced structural changes in the transverse processes (33). As a consequence of LTV, secondary intervertebral disc degeneration or CES may develop. The latter refers to a group of signs accompanying the compression of spinal nerve roots in the last segments of the spinal cord (18).

An asymmetrical transitional vertebra may additionally interfere with the correct positioning of the dog during examination, e.g. for hip dysplasia, as well as accelerate the development of the dysplasia (16). LTV symptoms have been shown to typically arise from intervertebral disc degeneration and CES. This involves pain and tenderness in the lumbosacral region, resulting in an unwillingness to stand or sit up. Hyperesthesia may be exacerbated by the compression or inflammation of spinal meninges and spine nerve roots in the course of CES. The compression is from the bony structures of the lumbosacral region, the L7-S1 intervertebral disc, or the L7-S1 intervertebral joint capsules. In orthopedic and neurological examination, dogs with CES often show pain at hip extension, which may be due to the fact that the spinal nerves are pulled when the joint extends. Hyperextension of the lumbosacral segment of the spine is also painful. Other symptoms result from nerve conduction disorders in the afferent proprioceptive fibers at the level of the lumbosacral spine. Even minor abnormalities in these fibers may delay the proprioceptive positioning reflex. Advanced disease may be associated with ataxia and impaired sensation in the pelvic limbs. In some cases, if the caudal segment of the spinal cord is damaged, tail mobility may be reduced due to a decreased muscle tone in the lumbosacral area. Sacral segment or sacral

nerve root damage may result in bladder and bowel incontinence (9).

Considering the prevalence of lumbosacral spine pathology in German Shepherds, we performed a study to develop a mathematical model describing the height and length of each lumbosacral vertebra in clinically healthy dogs. The present paper complements and elaborates on previous analyses (31). In the study, we want to verify whether the presence of spinal pathologies in German Shepherd dogs had a significant impact on the shape of particular elements of the spine. The aim of the study was to examine how the presence of spine pathology affects the shape of the lumbar spine and dimensions of individual vertebrae.

Material and methods

The research material consisted of radiological images of German shepherd dogs ($n = 54$), adult individuals of both sexes. Images were obtained in the years 2014-2019. All dogs selected for the study were purebred German Shepherd.

All dogs were patients of Warsaw's veterinary clinics. Dogs included in the study underwent radiographic examination of the lumbosacral spine for different reasons (check-up, lumbar pain, or suspected disease). However, no dog was examined exclusively for the purposes of the present study. The dogs were divided into two groups: specimens with no observable abnormalities in the spine ($n = 23$) and ones with identified pathologies ($n = 31$). The group with lumbar pathologies was further broken down into subgroups with spondylosis, with transitional vertebrae, and with spondylosis and transitional vertebrae. The personal details of the owners were not included in the survey.

X-ray images were selected according to specific criteria. The first criterion was the method by which the image had been taken (description below). The second criterion was the dog's breed. The X-ray images were examined by radiologists from Warsaw veterinary clinics, and additionally by the authors of the present paper.

The digital X-ray images for measurements were produced at small animal clinics in Warsaw, using the EXAMION® Maxivet 300 HF system. Depending on the individual dog's size, the voltage ranged between 76 and 54 kV, and the current ranged between 16 and 20 mA. These values were used for a film-focus distance of 100 cm. All X-ray images were taken by radiologists and one of the authors of the present paper. During the X-ray examination, the dogs were placed in the left lateral recumbency. The limbs were positioned caudally and secured with a sandbag. The head was kept in a natural position, with the neck supported with foam or a sandbag. The collimation included T12 and S1. The central ray was directed at L4. Before the examination, dogs were tranquilized using a mixture of medetomidine (Dexdomitor, 0.01-0.02 mg/kg b.w.), butorphanol (Morphasol, aniMedica GmbH, 0.1-0.5 mg/kg b.w.), and ketamine (Vetaketam, VET-AGRO Sp. z o. o., 2-5 mg/kg b.w.), administered intramuscularly.

Three measurements were taken from the X-ray images for each lumbar vertebra. The first measurement was taken from the top of the spinous process to the center of the spinal

cord. The second measurement was taken from the center of the body of one vertebra to the center of the body of the next one. The third measurement was of the height of the spinal canal. All measurements were made using the RadiAnt DICOM Viewer software.

The results of the three measurements of each vertebra were used for mathematical analysis. Using the R software version 4.0.3. and its base and stats packages, we determined the minimum and maximum value, range, mean, median,

and standard deviation. The stats package also includes the Shapiro-Wilk test, which was used to verify distribution normality in the data collected, and one-way ANOVA, used to check for correlations between the parameters measured and the diseases studied.

Results and discussion

We measured the spinous process heights and the distance between the lumbar vertebrae (Fig. 1). Then we calculated the summary position of subsequent lumbar vertebrae relative to the first lumbar vertebra, and the spinal canal height for the entire sample, for dogs without LTV and for dogs with LTV.

The basic statistical parameters for these measurements are listed in Tables 1, 2, 3, and 4, respectively.

Based on the measurements taken, dis-



Fig. 1. Measurement of the height of the spinous processes and the distance between the lumbar vertebrae in one of the dogs

Tab. 1. Basic statistical parameters for spinous process heights in the entire sample, in dogs without LTV, and in dogs with LTV

All dogs								
	L1	L2	L3	L4	L5	L6	L7	L8
min	30.90	34.30	37.00	39.20	40.30	36.30	32.80	20.10
max	49.00	54.20	55.30	56.80	56.20	53.30	47.80	32.80
range	18.10	19.90	18.30	17.60	15.90	17.00	15.00	12.70
mean	39.90	43.66	46.33	48.04	48.68	46.56	39.72	27.42
median	40.55	43.55	45.60	48.45	49.15	46.95	39.70	27.50
sd	3.78	4.15	4.56	4.40	4.03	4.24	3.95	3.29
Dogs without LTV only								
	L1	L2	L3	L4	L5	L6	L7	
min	34.30	37.60	38.70	39.20	40.50	37.70	32.80	
max	49.00	54.20	55.30	56.80	56.20	53.30	47.80	
range	14.70	16.60	16.60	17.60	15.70	15.60	15.00	
mean	40.63	44.60	47.27	48.82	49.22	46.95	39.86	
median	40.90	45.00	47.80	50.00	50.80	47.70	39.70	
sd	3.58	3.96	4.51	4.42	4.12	4.35	4.28	
Dogs with LTV only								
	L1	L2	L3	L4	L5	L6	L7	L8
min	30.90	34.30	37.00	39.20	40.30	36.30	33.70	20.10
max	42.00	43.60	45.40	50.10	50.50	48.50	41.40	32.80
range	11.10	9.30	8.40	10.90	10.20	12.20	7.70	12.70
mean	37.05	39.98	42.65	44.97	46.54	45.06	39.17	27.42
median	36.60	40.50	43.70	45.10	46.60	45.30	39.70	27.50
sd	3.27	2.58	2.44	2.75	2.90	3.54	2.29	3.29

Tab. 2. Basic statistical parameters for distances between the lumbar vertebrae in the entire sample, in dogs without LTV, and in dogs with LTV

All dogs							
	L1-2	L2-3	L3-4	L4-5	L5-6	L6-7	L7-8
min	34.90	35.90	32.60	37.80	37.80	35.00	31.50
max	45.60	47.30	47.90	48.70	49.50	45.00	37.20
range	10.70	11.40	15.30	10.90	11.70	10.00	5.70
mean	39.29	40.60	41.31	42.26	42.90	39.41	34.30
median	39.05	40.15	41.05	42.00	42.60	39.25	34.20
sd	2.51	2.58	2.82	2.47	2.59	2.41	2.01
Dogs without LTV only							
	L1-2	L2-3	L3-4	L4-5	L5-6	L6-7	
min	34.90	35.90	32.60	37.80	37.80	35.00	
max	45.60	47.30	47.90	48.70	49.50	45.00	
range	10.70	11.40	15.30	10.90	11.70	10.00	
mean	39.41	40.74	41.47	42.40	43.01	39.28	
median	39.00	40.50	41.40	42.10	42.60	39.10	
sd	2.77	2.85	3.11	2.69	2.82	2.63	
Dogs with LTV only							
	L1-2	L2-3	L3-4	L4-5	L5-6	L6-7	L7-8
min	37.20	38.70	39.00	40.00	40.20	38.10	31.50
max	40.10	41.80	42.10	44.00	44.00	41.60	37.20
range	2.90	3.10	3.10	4.00	3.80	3.50	5.70
mean	38.83	40.07	40.70	41.68	42.45	39.90	34.30
median	39.10	40.10	40.90	41.50	42.50	39.90	34.20
sd	0.83	0.94	0.98	1.17	1.35	1.15	2.01

Tab. 3. Basic statistical parameters for the summary position of subsequent lumbar vertebrae relative to the first lumbar vertebra in the entire sample, in dogs without LTV, and in dogs with LTV

All dogs							
	W2	W3	W4	W5	W6	W7	W8
min	34.90	70.80	108.50	147.00	185.00	220.70	266.80
max	45.60	92.60	140.50	189.20	238.70	283.60	287.50
range	10.70	21.80	32.00	42.20	53.70	62.90	20.70
mean	39.29	79.89	121.21	163.46	206.36	245.76	277.93
median	39.05	79.20	120.65	162.35	205.80	245.10	279.30
sd	2.51	5.03	7.63	10.02	12.52	14.58	6.36
Dogs without LTV only							
	W2	W3	W4	W5	W6	W7	
min	34.90	70.80	108.50	147.00	185.00	220.70	
max	45.60	92.60	140.50	189.20	238.70	283.60	
range	10.70	21.80	32.00	42.20	53.70	62.90	
mean	39.41	80.15	121.62	164.02	207.03	246.31	
median	39.00	79.70	121.40	164.40	207.70	246.80	
sd	2.77	5.56	8.43	11.05	13.79	16.15	
Dogs with LTV only							
	W2	W3	W4	W5	W6	W7	W8
min	37.20	76.10	115.10	155.10	195.30	234.30	266.80
max	40.10	81.90	124.00	168.00	212.00	251.00	287.50
range	2.90	5.80	8.90	12.90	16.70	16.70	20.70
mean	38.83	78.90	119.60	161.28	203.73	243.63	277.93
median	39.10	78.80	119.30	161.60	203.70	244.10	279.30
sd	0.83	1.72	2.55	3.62	4.81	5.04	6.36

tribution normality was verified for the spinous process heights in all lumbar vertebrae, distances between the vertebrae, the summary position of the vertebrae relative to the first one, and spinal canal height in the German Shepherd dogs. The distributions of most characteristics did not deviate from normal. Values that did not have a normal distribution included the distances between vertebrae L1-L2 and L2-L3, the position of vertebrae L2 through L5 relative to the first lumbar vertebra, and the spinal canal height for vertebra L2.

In the next stage, we analyzed the vertebrae of German Shepherd dogs with no abnormalities in the lumbosacral region of the spine observable in X-ray images.

In the group of clinically healthy German Shepherds, our analysis revealed the following characteristics that did not have a normal distribution: spinous process heights for vertebrae L4 and L5, L1-L2

Tab. 4. Basic statistical parameters for spinal canal height in each of the lumbar vertebrae in the entire sample, in dogs without LTV, and in dogs with LTV

All dogs								
	LR1	LR2	LR3	LR4	LR5	LR6	LR7	LR8
min	8.40	8.60	8.80	9.90	9.80	8.20	7.30	5.90
max	12.90	13.00	13.20	13.20	13.40	13.30	11.10	8.80
range	4.50	4.40	4.40	3.30	3.60	5.10	3.80	2.90
mean	10.68	10.87	11.06	11.56	11.59	10.82	9.25	7.35
median	10.60	10.90	11.05	11.50	11.50	10.85	9.20	7.40
sd	0.87	0.88	0.85	0.78	0.83	0.92	0.85	0.93
Dogs without LTV only								
	LR1	LR2	LR3	LR4	LR5	LR6	LR7	
min	8.40	8.60	8.80	9.90	9.80	8.20	7.30	
max	12.90	13.00	13.20	13.20	13.40	12.60	11.10	
range	4.50	4.40	4.40	3.30	3.60	4.40	3.80	
mean	10.59	10.79	11.00	11.53	11.54	10.76	9.20	
median	10.50	10.70	11.00	11.50	11.50	10.80	9.10	
sd	0.85	0.89	0.87	0.79	0.86	0.89	0.86	
Dogs with LTV only								
	LR1	LR2	LR3	LR4	LR5	LR6	LR7	LR8
min	9.90	10.30	10.40	10.60	10.50	9.20	8.30	5.90
max	12.70	12.70	12.70	13.00	13.00	13.30	10.90	8.80
range	2.80	2.40	2.30	2.40	2.50	4.10	2.60	2.90
mean	11.03	11.16	11.27	11.66	11.80	11.05	9.47	7.35
median	10.90	11.10	11.10	11.50	11.60	11.00	9.50	7.40
sd	0.89	0.79	0.80	0.79	0.69	1.04	0.78	0.93

distance, and L2 position relative to the first lumbar vertebra. We also performed a statistical analysis of measurement results in dogs with spinal abnormalities,

Tab. 5. Correlation of the measured parameters with LTV, spondylosis, and spondyloarthritis

Heights of the first five vertebrae							
	L1	L2	L3	L4	L5	L6	L7
LTV	0.00397	0.000581	0.00196	0.00831	0.0472	–	–
spondylosis	0.00778	0.0176	0.0473	0.0168	0.0168	–	–
spondyloarthritis	0.024	–	–	–	0.0286	0.0318	–
Distance between the centers of subsequent vertebrae							
	L1-2	L2-3	L3-4	L4-5	L5-6	L6-7	
spondylosis	0.0289	0.00606	0.0053	0.00159	0.00325	0.0316	
spondyloarthritis	0.00842	0.00641	0.00777	0.00389	0.00315	0.00131	
Summary position relative to the first vertebra							
	W2	W3	W4	W5	W6	W7	
spondylosis	0.0289	0.0126	0.00737	0.00485	0.00417	0.00483	
spondyloarthritis	0.00842	0.00665	0.00547	0.0047	0.00404	0.00265	
Spinal canal height							
	LR1	LR2	LR3	LR4	LR5	LR6	LR7
spondylosis	–	–	–	–	–	0.0356	0.0113

followed by distribution normality analysis. For dogs with a transitional vertebra, L3 spinous process height was the only value without a normal distribution.

Based on the above analysis, we identified a correlation between the heights of the first five vertebrae and the presence of an LTV (p-value in the table). No such correlation was found for summary distance between vertebrae or spinal canal height (Tab. 5).

In the group of German Shepherd dogs with spondylosis, we found a correlation between the heights of the first five vertebrae, distances between the vertebrae, and the summary position of the vertebrae relative to the first one. Spondylosis was most commonly accompanied by an alteration of distances between lumbar vertebrae, but was not correlated with spinal canal height. Similarly, in dogs with spondyloarthrosis, a statistically significant correlation also existed with vertebral height, distance between vertebrae, and summary position relative to the first vertebra. Spondyloarthrosis did not, however, affect spinal canal height.

Spondylosis is more common in older dogs and is not a congenital defect. It does, however, have a significant impact on distances between the vertebrae, which may be due to the formation of exostoses. As a consequence, these exostoses dilate the intervertebral spaces, increasing the distance between the bodies of the subsequent vertebrae.

Past research indicates that the locations most susceptible to spondylosis include spaces between vertebrae L2-L3 (38.78%), T12-T13 (31.63%), L1-L2 (31.63%), T5-T6 (28.57%), and L7-S1 (27.55%) (29). In our analysis, spondylosis was found most often in vertebrae L1-L3, which is consistent with the literature data.

An analysis of a graph illustrating lumbar vertebrae parameters in dogs with a transitional vertebra (LTV) demonstrated a considerable shift, indicating that the shape of specific vertebrae in these dogs was different. A statistical analysis of the data revealed a significant correlation between the heights of the spinous processes in the first five vertebrae and the presence of an LTV. Different literature sources place the prevalence of LTV in German Shepherds at between 4.3% and 29.0% (7, 33).

In studies carried out in the Czech Republic, as many as 10% of all studied dogs (n = 1878) of different breeds were found to have LTV. The abnormality was the most common in German Shepherds, with a prevalence of 25.9% (n = 53) (11).

In Germany (33), the prevalence of LTV in German Shepherd dogs was similar to that found in the Czech Republic (28.2%). A higher prevalence was recorded in Finland, reaching 40% (n = 92) of all dogs in the study (18). The differences in the numbers of dogs of specific breeds in each study may result from different national preferences (7, 12). This may, however, also be a reflection of how common the defect is. According to the literature report, dogs with LTV are more likely to

develop CES, which happens approximately 1.5 years earlier in these dogs than in ones without LTV (7). It is possible that the altered shape of the spine accelerates the development of the syndrome. Possibly, by studying the shape of the spine, one could determine the risk of CES.

Since lumbosacral spine pathologies are common, it is important to understand the biomechanics and morphology of each vertebra in the region. The impact of specific spinal abnormalities on the shape of other vertebrae and its potential consequences are also of considerable interest. The spine is an important factor in the assessment of and research on a variety of conditions. Dog skeleton models have long been used in experimental studies on biomechanics (23, 28) as well as a variety of spinal grafts and substitutes (10, 13, 24). This is why an understanding of normal canine spine morphometry is essential to future clinical studies. Despite continued research on lumbar spine pathology, the identified prevalence of specific conditions depends on factors such as the study location, the popularity of specific breeds, and time that has passed since the study (7, 11, 33). In human medicine, such analyses and similar projects are much more common. One example is a study by Abu-Leil et al. (1) for lumbar degenerative spondylolisthesis or morphometric analyses of the thoracolumbar and lumbar vertebrae in the Greek population based on computed tomography (15).

In conclusion, it should be emphasized that lumbar spine abnormalities were found in more than half of the dogs, which confirms that the German Shepherd is particularly predisposed to spinal disease. Spondylosis is most commonly identified in vertebrae L1-L3.

Our data do not show any significant impact of spondylosis on the shape of the spine in dogs. This may be due to the fact that it is an acquired condition, much more common in older dogs than in younger ones. The presence of a transitional vertebra does significantly affect the shape of the spine, and thus may lead to the development of other spinal abnormalities. Due to the high prevalence of LTV in German Shepherd dogs, we recommend X-ray screening for LTV in dogs of breeds predisposed to this abnormality, and we advise against using dogs affected by this condition in breeding.

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