Three-dimensional motion pattern of the caudal lumbar and lumbosacral portions of the vertebral column of dogs

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Objective—To evaluate the 3-dimensional motion pattern including main and coupled motions of the caudal lumbar and lumbosacral portions of the vertebral column of dogs.

Animals—Vertebral columns of 9 German Shepherd Dogs (GSDs) and 16 dogs of other breeds with similar body weights and body conditions.

Procedure—Main and coupled motions of the caudal lumbar and lumbosacral portions of the vertebral column (L4 to S1) were determined by use of a testing apparatus that permitted precise application of known pure moments to the vertebral column. Motion was compared between GSDs and dogs of other breeds.

Results—All specimens had a similar motion pattern consisting of main motion and a certain amount of coupled motion including translation. Vertebral columns of GSDs had significantly less main motion in all directions than that of dogs of other breeds. Translation was similar in GSDs and dogs of other breeds and was smallest at the lumbosacral motion segment.

Conclusions and Clinical Relevance—Results indicated that motion in the caudal lumbar and lumbosacral portions of the vertebral column of dogs is complex and provided a basis for further studies evaluating abnormal vertebral columns. (*Am J Vet Res* 2004;65:544–552)

Lumbosacral stenosis can develop secondary to trauma, neoplasia, discospondylitis,[1-3] and degeneration of the lumbosacral disk, which is the most common cause of cauda equina compression in nonchondrodystrophic, large-breed dogs.[4,5] Lumbosacral stenosis is characterized by intervertebral disk degeneration, disk herniation, osteophyte formation at the vertebral end plates and facet joints, and thickening of the ligaments and facet joint capsules,[5-8] leading to a narrow vertebral canal or intervertebral foramina.[8,9] Animals most commonly affected by **degenerative lumbosacral stenosis (DLSS)** are middle-aged, male **German Shepherd Dogs (GSDs)**.[10-15]

Causes for the high prevalence of lumbosacral disk degeneration in the GSDs are unknown. Congenital and developmental factors, instability, and mechanical load at the lumbosacral junction may play a role in the pathogenesis of DLSS. In GSDs, compared with other large-breed dogs, early lumbosacral disk degeneration has been detected in dogs < 1 year of age,[a,b] which may indicate a congenital metabolic or developmental origin. However, those authors could not explain why only the lumbosacral disk was affected, but not the other intervertebral disks of the lumbar portion of the vertebral column. Sacral osteochondrosis, in which the attachment of the disk to the end plate is damaged, is always associated with disk degeneration.[16] An association has been described between transitional vertebrae, cauda equina syndrome, and degenerative disk disease.[17] Because transitional vertebrae may result in asymmetry of the lumbosacral junction including the disk space, altered mechanical stress on the disk could result in disk degeneration. The GSD is over-represented in the population of dogs with sacral osteochondrosis and transitional vertebrae.[16,18,19]

Many studies have examined lumbosacral conformation and mobility in normal and affected dogs. Malalignment, described as ventral displacement of the sacrum, was considered a clinical sign of lumbosacral instability, which could lead to disk degeneration.[2,9,10,12] Results of studies[20,21] with vertebral columns of humans indicate that lumbar disk degeneration in an early stage caused segmental instability that mainly affected translational motion. However, in severely degenerated disks, motion was reduced.[20,21] Therefore, disk degeneration may be the cause, not the result of ventral displacement of the sacrum. In addition, ventral displacement of the sacrum is not always associated with clinical signs and can be found in dogs with and without cauda equina compression.[22,23]

Mobility, defined as the difference between the lumbosacral angle in flexion and the lumbosacral angle in extension, increases within the lumbar portion of the

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vertebral column from cranial to caudal with the highest values at L7-S1.[24,25] The lumbosacral angle is defined as the angle between 2 lines bisecting L7 and S1 longitudinally or the lines marking the floor of the vertebral canal. In neutral position, it is slightly angled dorsally at the lumbosacral level.[3,10,22] Breed and size do not influence the mobility of the lumbosacral junction.[22,25] Female dogs have a higher mobility in the lumbosacral junction than male dogs[24]; however, males have a higher prevalence of DLSS.[10,12-14] Both of these findings indicate that the amount of motion alone does not explain the high prevalence of DLSS in GSDs. The main type of motion is rotation with the disk as the fulcrum combined with a small amount of translation resulting in ventral displacement of the sacrum.[24] Dogs affected by DLSS had reduced flexion in the lumbosacral junction leading to reduced mobility.[22] Because those mobility studies were performed in dogs during general anesthesia or with cadaver specimens, the changes in lumbosacral motion reflect an actual biomechanical dysfunction rather than active resistance to pain.

Many questions remain open regarding the biomechanical function of the lumbar portion of the vertebral column. Single aspects of lumbosacral motion have been evaluated in the lumbar portion of the vertebral column in dogs, but all of the parameters were examined in the 2-dimensional sagittal plane. However, motion is a complex **3-dimensional (3-D)** process, and it is important to understand the normal kinematics to be able to determine the impact of morphologic aspects and structural pathologic conditions on the motion of the lumbar portion of the vertebral column. The purpose of the study reported here was to evaluate the 3-D motion pattern, including main and coupled motions of the caudal lumbar and lumbosacral portions of the vertebral column of dogs.

Materials and Methods

Twenty-five caudal lumbar portions of the vertebral column (L4 through the sacrum) of dogs euthanatized for nonskeletal diseases were obtained. Specimens of 9 GSDs and 16 dogs of other breeds (Bernese Mountain Dog [n = 4], Golden Retriever [3], Labrador Retriever [2], Flat Coated Retriever [1], Rhodesian Ridgeback [1], American Staffordshire Terrier [1], Standard Poodle [1], Belgian Tervueren [1], Dutch Shepherd [1], and Border Collie cross [1]) with similar body weight were used. Dogs were from 1 to 14.2 years old. There were 8 females and 17 males. Only vertebral columns without any radiographic evidence of degeneration were used. Helical multislice **computed tomography (CT)** was performed to assess the morphology of the vertebrae immediately before testing.[c] Technique settings were 80 kilovolt (peak) and 80 mA. Contiguous 1.25-mm-thick transverse slices were obtained from the midbody of L4 through the sacrum. Specimens were evaluated for degenerative lesions (spondylosis, osteophytes at the facet joints, or subchondral sclerosis). At the end of all procedures, the intervertebral disks were assessed by use of high-field **magnetic resonance imaging (MRI**; 1.5 T) with a dedicated circular polarized human extremity coil.[d] In the sagittal plane, T2-weighted 3-D free induction steady state precession gradient recalled echo (fat saturation; **time to echo [TE]**, 10 milliseconds; **repetition time [TR]**, 30 milliseconds; flip angle, 40°; 1 mm), T2-weighted **turbo spin echo (TSE**; TE, 98 milliseconds; TR, 3,000 milliseconds; 2 mm), and T1-weighted TSE (TE, 17 milliseconds; TR, 526 milliseconds; 2 mm) sequences and in the transverse plane, T1-weighted TSE (TE, 18 milliseconds; TR, 533 milliseconds; 2 mm) sequences were obtained. Intervertebral disks were assessed for degeneration according to a recently published classification system.[26] Criteria for evaluation of disk degeneration were signal intensity of the nucleus pulposus on T2-weighted images and integrity of the annulus fibrosus on T1-weighted images.

Vertebral columns were dissected of all nonligamentous soft tissue. Specimens were frozen at –20°C and thawed for approximately 16 hours at 22°C before testing. The cranial portion of the L4 vertebral body and the sacrum were embedded in **polymethylmethacrylate**[e] **(PMMA)** with the horizontal plane set level with the middle of the intervertebral disks. Screws drilled into the sacrum and the vertebral body and spinous process of L4 ensured a strong connection between the PMMA and the bony tissue.

Each specimen was mounted in a testing apparatus that permitted the precise application of specified pure moments to the vertebral column (**Fig 1**). The caudal PMMA block with the embedded sacrum was fixed and remained stationary during testing. On the cranial PMMA block, a torque wheel was mounted that had steel cables that permitted the application of pure moments without constraining the movement of L4. Moments of flexion, extension, lateral bending to the right and left, and axial rotation to the right and left were applied stepwise to a maximum of 3 **Newton meters (Nm**; 4 steps of 0.75 Nm). Testing was performed during 3 cycles in each direction to precondition the specimens and minimize the viscoelastic effects of the specimens. The third cycle was used for analysis. At each load, the torque was held for 30 seconds to permit equilibration of the specimen. Specimens were wrapped in wet towels during the entire procedure to prevent dehydration of the ligaments.[27]

The motion of each vertebra in relation to the caudal vertebra was measured by use of an optoelectronic camera system.[f] The system monitored the position of marker carriers fixed on every vertebral body. Each marker carrier had 4 noncolinearly arranged infrared light-emitting diodes. For each applied moment, the complete motion of the cranial vertebra in relation to the caudal vertebra consisted of 6 degrees of freedom (3 rotations and 3 translations). Motion was described in biomechanics in relation to a coordinate system placed into the body[28] (**Fig 2**). In our specimens, the origin was located at the cranial border of the sacrum. The positive y-axis points cranially, the positive z-axis points ventrally, and the positive x-axis points toward the left side. The direction opposite to the arrows was negative. Looking in the positive direction of the axis from the origin, clockwise rotations were positive (+) and counterclockwise rotations were negative (–). Thus, +x was flexion, –x was extension, +y was axial rotation to the left, -y was axial rotation to the right, +z was right lateral bending, and –z was left lateral bending. To get the range of motion, the maximum rotation in the positive and negative directions was added. Main motion was defined as motion in the direction of the applied moment. Coupled motion was associated motion about a second axis. Translation, where 2 vertebrae move parallel to each other along each of the 3 axes, can also be regarded as coupled motion. Translation of the cranial vertebra along the coordinate axes was calculated relative to the caudal vertebra. Translation along the x-axis described the movement of the vertebrae to the right (–x) and to the left (+x). Translation in the cranial direction was +y, caudal direction was –y, ventral translation (the cranial vertebra moves ventrally, compared with the caudal vertebra) was +z, and dorsal translation was –z.

This technique permits the vertebral column to move freely in its natural motion pattern and provides a noncontacting motion measurement of the specimen. In our study, the measurement error of the motion measurement system was determined as 0.3 mm for translation and 0.1° for rotation.

Before starting the test, a lateral radiograph was obtained and digitized to provide information about the geometric association between the anatomic coordinate system and the corresponding markers.

The relative vertebral motions were calculated in terms of Euler angles by use of the angle sequence ZYX. The motion pattern of all specimens was determined, and GSDs were compared with dogs of other breeds.

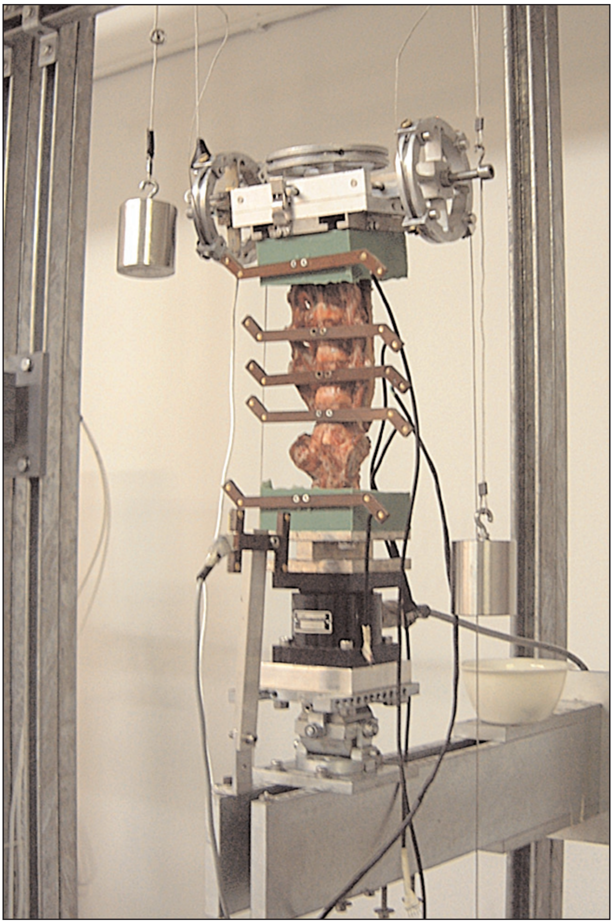

Figure 1—Photograph of the apparatus used to test motion patterns of the lumbar and lumbosacral portions of the vertebral column of 25 dogs. The cranial portion of the L4 vertebral body and the sacrum are embedded in polymethylmethacrylate (PMMA) with the sacrum fixed to the apparatus. A torque wheel is mounted on the cranial PMMA block, and steel cables permit application of known pure moments to the vertebral column. A marker carrier with 4 integrated, noncolinearly arranged, infrared light-emitting diodes is fixed on each vertebral body. On each side, a counterweight to the torque wheel is attached.

Statistical analyses—Descriptive analyses of the data indicated symmetrical distribution of the sampled data, and results are given as mean ± SD. Effects of age, sex, level (motion segment), and breed on motion pattern were estimated by use of distinct linear models for each direction. Assumptions of normal distribution were verified by residual analysis and evaluation of correlation coefficients (r^2). All models accounted for reasonable amounts of variation in the respective target variables, and power calculations were performed for all models. All statistical analyses were performed by use of computer software,[g] and throughout the study, a value of $P < 0.05$ was considered significant.

Results

There were no significant differences in age and sex distribution between GSDs and dogs of other breeds.

In the CT images, a few facet joints with minimal degenerative changes such as small osteophytes (GSDs [n = 1], other breeds [5]) or a slightly thickened sub-

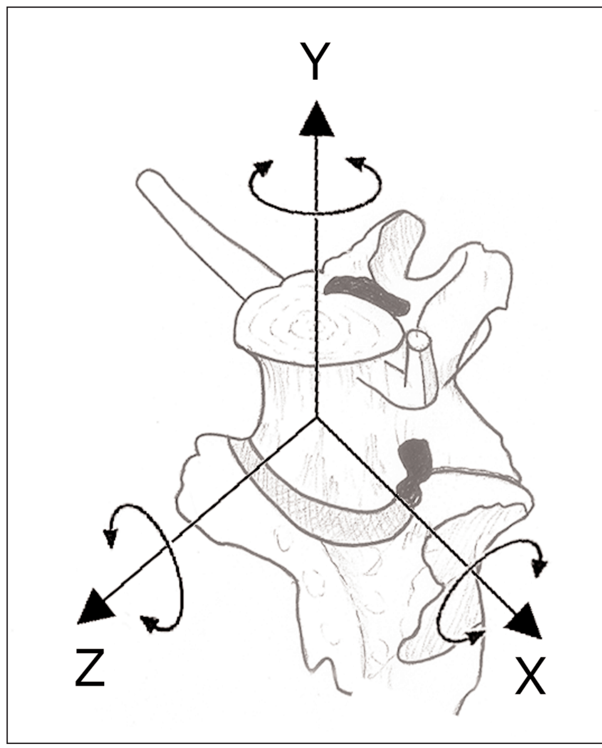

Figure 2—Three-dimensional coordinate system placed into a lumbosacral motion segment of the vertebral column. Motion around the x-axis was flexion (+x) and extension (–x), around the y-axis was axial rotation (axial rotation to the left, +y; axial rotation to the right, –y), and around the z-axis was lateral bending to the right (+z) and left (–z).

Table 1—Mean ± SD values for main (bold) and coupled motion at all levels of the caudal lumbar and lumbosacral (L4 through S1) portion of the vertebral column of 25 dogs

	Flexion & extension			Axial rotation			Lateral bending		
Level	X	Y	Z	X	Y	Z	X	Y	Z
L4-5	**7.2 ± 2.0**	0.8 ± 0.9	1.4 ± 1.4	1.4 ± 0.9	**1.9 ± 0.9**	1.4 ± 0.9	2.5 ± 1.6	2.4 ± 1.9	**19.0 ± 4.0**
L5-6	**6.8 ± 1.9**	1.1 ± 0.9	0.9 ± 0.6	1.0 ± 0.9	**0.8 ± 0.6**	0.5 ± 0.4	2.3 ± 2.0	0.8 ± 0.6	**4.1 ± 3.4**
L6-7	**11.8 ± 2.9**	1.3 ± 1.2	0.8 ± 0.7	0.9 ± 0.6	**0.7 ± 0.5**	0.8 ± 0.7	1.8 ± 1.4	1.0 ± 0.8	**7.1 ± 3.5**
L7-S1	**37.0 ± 5.7**	1.4 ± 1.5	1.2 ± 0.9	1.8 ± 1.2	**2.0 ± 1.2**	0.7 ± 0.7	2.8 ± 1.6	2.7 ± 1.5	**9.5 ± 2.6**

Units are in degrees. X = Flexion and extension. Y = Axial rotation. Z = Lateral bending.

chondral bone plate (GSDs [1], other breeds [1]) were recognized. Four vertebral end plates (GSDs [n = 2], other breeds [2]) had spondylosis in an early stage. One intervertebral disk had a slight bulging (other breeds [1]).

Seventy-six intervertebral disks (GSDs [n = 29], other breeds [47]) were classified as normal (stage 1) on MRI. Eighteen intervertebral disks (GSDs [n = 6], other breeds [12]) had reduced signal intensity on T2-weighted images (stage 2), and 4 dogs of other breeds had a protrusion of the lumbosacral disk (stage 3). Two intervertebral disks at the level of L4-5 were not assessed because of artifacts. Data from the kinematic analysis of the discovertebral junctions with a protrusion were excluded from the statistical analyses.

With flexion and extension as the main motion, the mean values were similar at L4-5 and L5-6, but revealed a significantly increasing range of motion from L5-6 to L7-S1 (**Table 1**). The highest mobility was detected at levels L6-7 with 11.8° and L7-S1 with 37°. German Shepherd Dogs (mean, 34.8°) had significantly less flexion and extension at L7-S1 than dogs of other breeds (mean, 38.7°). Coupled axial rotation and coupled lateral bending ranged from 0.8° to 1.4° (**Fig 3**).

In any given motion segment, translation could change direction from positive to negative and vice versa during a loading cycle. Despite these inconsistencies, observations about the motion pattern were made.

In extension, ventral translation of the cranial to the caudal vertebra (positive translation along the z-axis) at levels L4-5 to L6-7 was observed. The direction of translation at L7-S1 was inconsistent; 50% of dogs had ventral, and the other 50% had dorsal translation. In flexion, dorsal translation of the cranial to the caudal vertebra was predominating from L4-5 to L6-7. Again at L7-S1, translation in either direction was observed. Generally, translation was slightly greater in flexion than in extension and was significantly different between levels (**Table 2**). At L4-5 and L5-6, mean dorsoventral translation was 2.8 mm in flexion and 2.1 mm in extension. At L6-7, mean dorsoventral translation increased to 3.6 mm in flexion and 3.1 mm in extension. The smallest translation was detected at L7-S1, with 1.6 mm in flexion and 0.8 mm in extension. Lateral translation (along the x-axis) could be to the right or left and was mostly < 1 mm. Translation along the y-axis (axial translation) could be directed cranially or caudally at levels L4-5 to L6-7. Only at L7-S1, a constant pattern was observed. During flexion, cranial translation of the cranial vertebra (traction on the lumbosacral disk space) predominated, and during extension, caudal translation (compression) predominated. Axial translation was mostly < 2 mm between L4 and L7, and as much as 4 mm at L7-S1.

With axial rotation as the main motion, rotation in the long axis was small and decreased from L4-5 to L6-7 with the maximum range of motion at L7-S1 (2°; **Fig 4**). In dogs of other breeds, significantly more axial rotation was possible than in the group of GSDs at all levels except L4-5. Coupled flexion and extension decreased from L4-5 to L6-7, with the highest amount of motion detected at L7-S1 (1.8°). Coupled lateral bending was greatest at L4-5 (1.4°) and smallest at the other levels (0.5° to 0.7°). Translation along the z-axis varied substantially; it could be ventral or dorsal at all levels. The values were greatest cranially (L4-5) and smallest at the lumbosacral level (< 1 mm). Translation along the x-axis caused translation mainly in the same direction as the applied torque at L7-S1. Axial rotation to the right side caused translation to the right, and axial rotation to the left side caused translation to the left. At the other levels, no constant pattern was identified. The values were < 1.5 mm. Translation along the y-axis (translation in craniocaudal direction) could be positive or negative with values mostly < 1.5 mm.

During lateral bending, motion increased from L5-6 to L7-S1 (4.1° to 9.5°), but maximum range of motion was detected at L4-5 (19°; **Fig 5**). Dogs of other breeds had significantly greater motion from L5-6 to L7-S1 than GSDs. Coupled flexion and extension ranged

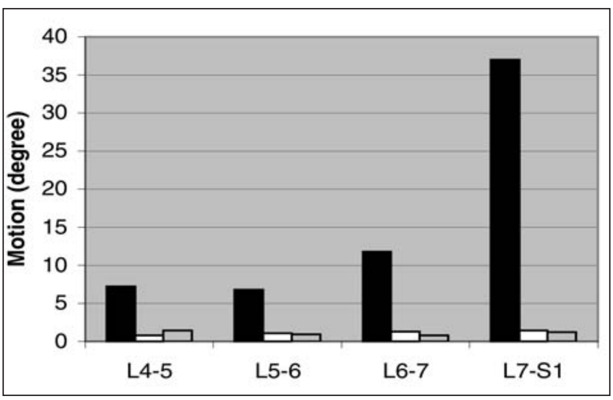

Figure 3—Mean values for flexion and extension (black bar) as the main motion with coupled axial rotation (white bar) and lateral bending (shaded bar) at all levels of the caudal lumbar and lumbosacral portion of the vertebral column of 25 dogs.

Table 2—Main motion (bold) and coupled translation (trans) at all levels of the lumbar and lumbosacral portion of the vertebral column of 25 dogs during flexion and extension, axial rotation, and lateral bending

	Flexion and extension				Axial rotation				Lateral bending			
Level	**X**	**Trans X**	**Trans Y**	**Trans Z F/E**	**Y**	**Trans X**	**Trans Y**	**Trans Z**	**Z**	**Trans X**	**Trans Y**	**Trans Z**
L4-5	**7.2**	< 1.0	< 2.0	2.8/2.1	**1.9**	< 1.5	< 1.5	< 3.0	**19.0**	< 6.0	< 5.0	< 5.0
L5-6	**6.8**	< 1.0	< 2.0	2.8/2.1	**0.8**	< 1.0	< 1.0	< 2.0	**4.1**	< 2.0	< 3.0	< 4.0
L6-7	**11.8**	< 1.0	< 2.0	3.6/3.1	**0.7**	< 1.0	< 1.0	< 1.5	**7.1**	< 2.5	< 2.0	< 3.0
L7-S1	**37.0**	< 1.0	< 4.0	1.6/0.8	**2.0**	< 1.0	< 1.5	< 1.0	**9.5**	< 1.0	< 4.0	< 2.0

Coupled translation is in millimeters. Main motion is in degrees. F/E = Mean dorsoventral translation in flexion and extension. Translation is depicted as mean at a load of 3 Newton meters regardless of whether the direction of translation was positive or negative.
See Table 1 for remainder of key.

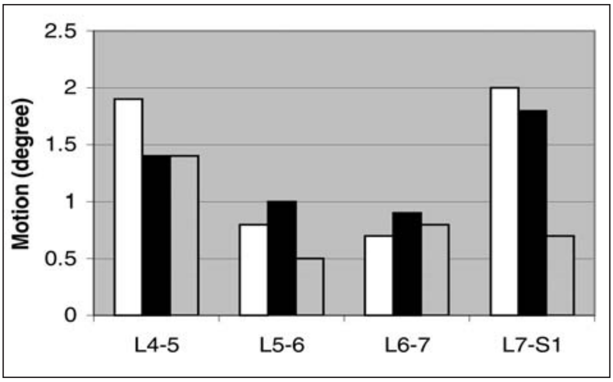

Figure 4—Mean values for axial rotation as the main motion with coupled flexion and extension and lateral bending at all levels of the caudal lumbar and lumbosacral portion of the vertebral column of 25 dogs. *See* Figure 3 for key.

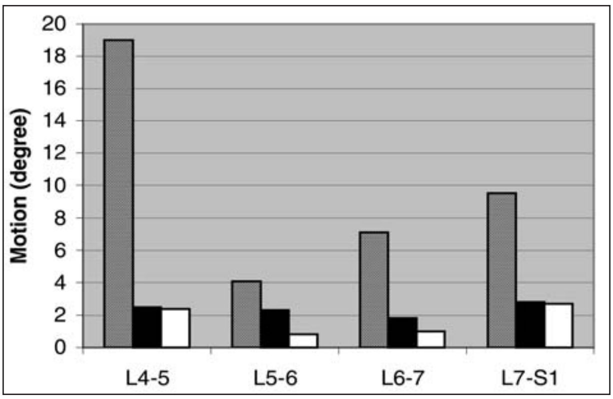

Figure 5—Mean values for lateral bending as the main motion with coupled flexion and extension and axial rotation at all levels of the caudal lumbar and lumbosacral portion of the vertebral column of 25 dogs. *See* Figure 3 for key.

from 1.8° to 2.8°, with the highest value at L7-S1. Coupled axial rotation was greatest at L7-S1 (2.7°) and L4-5 (2.4°). Translation along the z-axis varied substantially and could be ventral or dorsal at all levels. Ventrodorsal translation was greatest at L4-5 (as much as 5 mm) and decreased towards the lumbosacral junction (< 2 mm). Coupled translation along the x-axis was in the opposite direction than the primary motion and was most obvious from L4-5 to L6-7. Right lateral bending caused translation to the left, and left lateral bending caused translation to the right. At L7-S1, translation could go to the right or left of whatever direction the applied torque had. Translation along the x-axis decreased from L4-5 towards L7-S1. At L4-5, the values went as high as 6 mm, whereas at L7-S1, the values were < 1 mm. Translation along the y-axis (translation in craniocaudal direction) could be positive or negative and ranged between 0.5 and 5 mm.

Significant correlation between main and coupled motion was observed during axial rotation and lateral bending as main motions. Axial rotation was correlated (r^2 = 0.39) with lateral bending as coupled motion **(Table 3)**. Lateral bending was correlated (r^2 = 0.47) with axial rotation as coupled motion. For the main motions, the power of test ranged between 0.68 and 0.96.

The 4 specimens from dogs of other breeds with protrusion of the lumbosacral disk had significantly more flexion and extension at the lumbosacral level than the normal specimens of dogs of other breeds (with protrusion, flexion and extension was 50.8°; without protrusion, flexion and extension was 36.7°). Coupled flexion and extension during lateral bending was also significantly different; specimens with protrusion of the lumbosacral disk were more mobile than those of dogs of other breeds.

Table 3—Correlation coefficients of main and coupled motion in the caudal lumbar and lumbosacral portion of the vertebral column of 25 dogs

	Main motion		
Coupled motion	Flexion and extension	Axial rotation	Lateral bending
Flexion and extension	NA	0.23	0.0
Axial rotation	0.21	NA	0.47
Lateral bending	0.11	0.39	NA

NA = Not applicable.

Discussion

To the authors' knowledge, the study reported here is the first description of the 3-D motion pattern of the caudal lumbar and lumbosacral portions of the vertebral column of dogs. The testing procedure performed is a standardized and accepted method used to test the biomechanics of vertebral column specimens.[27] Specimens were dissected and frozen at –20°C within 2 days after dogs were euthanatized and thawed overnight (approx 16 hours) before testing. Freezing and storage, even for long periods, does not change the physical properties of vertebral column specimens.[29] The test setting permitted unconstrained movement of the specimens, and the loading protocol has been well-defined.[27,30] The orientation of the coordinate system was chosen in agreement with White and Panjabi.[28]

Computed tomography is the method of choice for assessing the morphology of vertebrae.[31] The slight degenerative changes observed in the lumbar and lumbosacral portions of the vertebral column were equally distributed between GSDs and dogs of other breeds. Because the degenerative changes were mild and the motion patterns were not different from the specimens without changes, we classified those vertebral columns as normal.

Magnetic resonance imaging is the method of choice for noninvasive assessment of the intervertebral disks in dogs and humans.[32-37] The sensitivity for detection of disk degeneration in dogs has been reported to be high.[26] The 4 vertebral columns with disk protrusion at L7-S1 had significantly more flexion and extension than specimens without a protrusion, and this may have been because of decreased tension and hydrostatic pressure in the intervertebral disk. The normal intervertebral disk is a firm structure that functions as a cushion. If material of the nucleus pulposus herniates, the intervertebral disk becomes more flexible. This observation parallels the findings of Seligman et al[20] and Fujiwara et al[21] who found increased segmental motion in humans with early intervertebral disk degeneration.

Direct comparison of results from studies of the lumbar portion of the vertebral column of humans and results of the study reported here is difficult. In most tests of the lumbar portion of the vertebral column from humans, only 1 motion segment is tested, whereas in this study with specimens from dogs, 4 motion segments were tested. Another difference is that the lumbosacral junction of dogs is more flexible, compared with that of humans. Therefore, a maximum load of only 3 Nm was chosen, whereas in most studies, vertebral columns from humans are tested at a load of 10 Nm. In preliminary tests, 3 Nm was determined to be sufficient to cause maximum physiologic motions, but small enough not to damage the specimen. Because of the in vitro nature of this study, the effect of vertebral muscles and body weight on motion was not determined. Direction and magnitude of the in vivo forces are unknown and obviously different between sexes, ages, and breeds.

In flexion and extension, motion increased exponentially from L5-6 to L7-S1 as seen in previous studies.[24,25] In our study, lumbosacral mobility, defined as the difference between the lumbosacral angle in flexion and the lumbosacral angle in extension, was comparable with results of other studies.[7,22,24,25,h] The slight differences of a few degrees between these studies may be explained by the variation in test settings. Some studies were performed with vertebral column specimens, others with living anesthetized animals. Therefore, the influence of muscle forces and muscle relaxation during anesthesia may have influenced the results. Range of motion is also influenced by the condition of the discovertebral junction and the dorsal elements, which include the facet joint capsules, ligamentum flavum, laminae, and pedicles of the vertebrae. These structures are stretched during flexion. As degeneration develops, these elements become rigid and flexion is reduced.[22] Results of another study[7] indicate that dogs with DLSS have increased dynamic malalignment, increased flexion, and decreased extension of the lumbosacral joint resulting in reduced lumbosacral mobility. However, results of that study are different from those of other studies[22,25] with similar test conditions and are biomechanically difficult to explain.

In the study reported here, males (mean, 37.9°) were slightly more flexible than females (35.1°); however, there was no significant difference in the range of motion at any level of the lumbar portion of the vertebral column between males and females. This is in accordance with Schmid and Lang[22] who did not find a difference in the mobility between sexes, whereas Bürger and Lang[24] found 9° more lumbosacral motion in female than male dogs. Different testing conditions combined with anatomical differences may have been a possible explanation for these differences. In Bürger and Lang[24] the specimens were moved manually up to the maximum flexion and extension. Because ligaments and muscles of females are smaller and softer than those of males and the applied force was not defined, it is possible that the ligaments of the female specimens were overstretched.

Lumbar portions of the vertebral column of GSDs were less flexible at L7-S1 than those of dogs of other breeds, whereas Schmid and Lang[22] found GSDs and other dogs to have lumbosacral mobility in the same magnitude. Those authors assessed radiographs of living dogs during general anesthesia. Therefore, part of the difference may be explained by muscle mass and muscle relaxation. In our study, the main motions in all directions were generally smaller in GSDs than in other dogs. The high mobility of the lumbosacral joint at a level where all the loading forces from the pelvis, sacroiliac joint, and sacrum are transmitted to the lumbar portion of the vertebral column may predispose to high wear and tear and may be a risk factor for disk degeneration; however, it cannot explain why GSDs are predisposed to DLSS since in this breed, mobility in the lumbosacral junction was smaller, compared with dogs of other breeds.

Because there is no information about the 3-D motion pattern in dogs, flexion and extension, axial rotation, and lateral bending of the caudal lumbar portion of the vertebral column of dogs will be compared with the motion pattern of the vertebral column of humans.[38-41] In flexion and extension, the vertebral columns of dogs were as much as 3 times as mobile as that of humans at the level of the lumbosacral junction. At the other levels, flexion and extension is similar between dogs and humans. Both have an increase of motion towards the more caudal motion segments. Coupled axial rotation and lateral bending are similar at all levels in vertebral columns of humans and dogs and range between 1° and 2°.[38]

In axial rotation, the motion pattern was different between species. Vertebral columns of humans have more axial rotation in the middle part of the lumbar portion of the vertebral column than at the most cranial portion and the lumbosacral levels.[38-40] Results of our study indicated an inverse motion pattern with most axial rotation detected at L4-5 and L7-S1, and the amount of axial rotation was generally smaller in the middle part of the lumbar portion of the vertebral column. Coupled flexion and extension is similar between species. Coupled lateral bending in vertebral columns of humans is approximately twice as high, compared with that in vertebral columns of dogs.[38]

Results of other studies[38,39] performed with vertebral columns of humans indicate that lateral bending ranges from 9° to 11° at all levels, whereas Pearcy[40] found a decrease in lateral bending from cranial (10°) to caudal (3°) levels.[4] This difference may be a consequence of the different test conditions. Pearcy[40] performed in vivo studies, whereas Panjabi et al[38] and Yamamoto et al[39] tested vertebral column specimens. In our study, the highest range of motion was observed at L4-5, with a significant decrease at L5-6 and a constant increase towards L7-S1. However, the motion pattern of vertebral columns of humans and dogs in lateral bending is completely different. In dogs, the magnitude of coupled flexion and extension and axial rotation followed the pattern of the main motion. Vertebral columns of humans had approximately 1° of coupled flexion at L1-2 and approximately 2° from L2-3 to L5-S1.[38] Coupled axial rotation was 2° at the cranial levels and as much as 4° at the caudal levels.[38]

The observed correlation between axial rotation and lateral bending may have been explained by structures that permit motion in both directions; therefore, motion in 1 direction was always accompanied by motion in the other direction. Because the facet joints have an oblique orientation, it is physically logical that lateral bending induces axial rotation and axial rotation can induce lateral bending.

Because the power of test is high (between 0.68 and 0.96) for the main motions, we determined that the number of specimens was representative for the amount of motion detected in the caudal lumbar and lumbosacral portions of the vertebral column.

The significance of the ventrodorsal translation of the sacrum in the pathogenesis of DLSS in dogs remains unknown. Some authors consider this as a clinical sign of instability[2,9,10,12]; however, ventrodorsal translation is not always associated with clinical signs or intervertebral disk degeneration.[22-24] Increased amount of extension was always found to cause an increasing amount of ventral translation of the sacrum. Maximum ventral translation was described to be greater in extension than in flexion.[3,h] In flexion, the direction of translation is inconsistent, can go ventrally or dorsally, and is smaller, compared with extension.[3,h] In our study, we also found translation at levels L4-5 to L6-7 during extension (ventral) and flexion (dorsal direction of the cranial to the caudal vertebra). At L7-S1, the vertebrae could move in either direction. On the basis of our results and compared with that of other studies,[2,9,10,12,22-24] normal ventrodorsal translation is difficult to assess. The amount and direction of translation were similar between all breeds and levels from L4-5 to L7-S1, with the least translation detected at the lumbosacral junction, the site in which intervertebral disk degeneration frequently develops (ie, increased ventrodorsal translation does not occur in normal, adult, large-breed dogs). Whether increased ventrodorsal translation is a primary problem leading to abnormal shearing forces and lumbosacral disk degeneration, or whether disk degeneration precedes increased translation, is not yet known. To the authors' knowledge, there have been no studies that investigate translation at levels other than L7-S1 and translation in other directions than along the z-axis (ventrodorsal) in veterinary medicine. Results of a study[38] performed with vertebral column specimens of humans are comparable to the motion pattern in dogs. Translation at all levels is generally small (< 2 mm) in all directions in human and canine specimens.

All canine specimens had a constant motion pattern in the caudal lumbar and lumbosacral portions of the vertebral column. Results of the study reported here indicated the complexity of motion in this region and provided a basis for further biomechanical studies and studies evaluating abnormal vertebral columns.

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[b]Hagen AP. *Alterung der Zwischenwirbelscheiben bei grosswüchsigen Hunderassen*. Doctoral thesis, Department of Animal-Pathology, University of Zürich, Switzerland, 1990.

[c]LightSpeed QX/I, GE Medical Systems, Buc, France.

[d]Magnetom sonata maestro class, Siemens AG, Erlangen, Germany.

[e]Beracryl, W. Troller, Fulenbach, Switzerland.

[f]Optotrak 3020, Northern Digital, Waterloo, ON, Canada.

[g]SAS Institute Inc, Cary, NC.

[h]Geissbühler AD. *Kinetische Studien am Lumbosakralen Übergang von Berner Sennenhunden und Deutschen Schäferhunden*. Doctoral thesis, Section of Radiology and Surgery/Orthopedics, Small Animal Hospital, University of Bern, Switzerland, 2000.

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