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# Relationship between the severity of neurological signs in dogs with thoracolumbar intervertebral disc disease and the magnitude of spinal cord compression by disc extrusion as assessed by computed tomography

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**Abstract**

The aim of this study was to verify the relationship between the degree of severity of neurological signs in dogs with thoracolumbar intervertebral disc disease (TL-IVDD) and the magnitude of spinal cord compression on the computed tomography (CT) transverse view of the vertebra at the site of the greatest narrowing of the spinal canal caused by extruded disc material. In a total of 78 dogs with TL-IVDD, the greatest narrowing of the spinal canal at the site of greatest spinal cord compression was observed in the T11-T12 region (48.35 ± 20.70%) and the smallest in the L2-L3 region (33.06 ± 15.40%). There was a significant difference in the percentage of spinal canal narrowing between the L2-L3 region and the T11-T12 ($P$ = 0.034), T12-T13 ($P$ = 0.033) and T13-L1 ($P$ = 0.022) regions, respectively. Females showed a significantly higher percentage of spinal canal narrowing compared to males ($P$ = 0.029); the highest percentage of spinal canal narrowing was found in neutered females compared to intact females ($P$ = 0.013), neutered males ($P$ = 0.029), and intact males ($P$ = 0.001), respectively. In addition, the dogs included in the study were divided into a group of chondrodystrophic (n = 55) and a group of nonchondrodystrophic (n = 23) dogs. Dogs of chondrodystrophic breeds generally showed a highly significantly ($P$ = 0.001) more severe degree of neurological signs compared to dogs of nonchondrodystrophic breeds. Results of this study can be useful in veterinary practice diagnostics.

*Protrusion, paraplegia, paraparesis, chondrodystrophic breed*

In the diagnosis of thoracolumbar intervertebral disc disease (TL-IVDD), characterized by the extrusion of disc material into the spinal canal (Gage 1975; Hoerlein 1978; Nečas 1999a; Nečas 1999b), imaging diagnostic techniques have traditionally been used, namely native radiological examination, myelography, computed tomography (CT), magnetic resonance imaging (MRI) and, among laboratory methods, cerebrospinal fluid examination or a combination of these (Da Costa and Samii 2010; Da Costa et al. 2020). Since 2000, CT scans and MRI scans of the spine have emerged as the most commonly used imaging modality (Da Costa et al. 2020).

It is known that the severity of spinal cord injury is influenced by a number of factors (Widmer and Thrall 2002; Griffin et al. 2009) and one of these is also the magnitude of spinal cord compression (Olsson 1958). As a modern and rapid imaging modality used in the diagnosis of TL-IVDD, CT represents one of the complementary options for relatively rapid preoperative prognostic assessment in dogs affected by thoracolumbar intervertebral disc herniation, if suitable methodology is used to image and measure the magnitude of spinal cord compression by disc material extruded into the spinal canal and to find any possible association with the severity of neurological impairment in the patient. Obviously, each of the imaging methods and each technique or method of measuring the effect of the magnitude of spinal cord compression by extruded disc material on the severity

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of clinical findings, has its limitations and may not be reliable in determining the possible relationship between the two. Potential correlations should be sought from this perspective. Several studies using diagnostic imaging have already examined the correlation between maximum transverse spinal cord compression ratio and severity of neurological status in dogs with type I TL-IVDH, finding that maximum transverse spinal cord compression ratio does not exhibit a significant association (Penning et al. 2006; Levine et al. 2009). However, another study demonstrated a moderate positive correlation between the severity of spinal cord compression and neurological impairment in dogs with cervical spondylomyelopathy (Bonelli et al. 2021). None of these studies evaluated the degree of compression that might influence the severity of neurological impairment, which remains a controversial subject (Penning et al. 2006; Levine et al. 2009; Bonelli et al. 2021; Sakaguchi et al. 2023).

For the above reasons, CT was the imaging modality of choice for this study in diagnosing TL-IVDD and verifying the potential relationship between the magnitude of spinal cord compression by extruded disc material and the severity of neurological impairment in dogs with TL-IVDD. Some of the characteristics examined by CT in dogs with TL-IVDD, such as the relative ratios of the spinal cord surfaces and the disc material extruded into the spinal canal on CT transverse sections of the vertebra at the site of intervertebral disc extrusion in the thoracolumbar spine, and their comparison in chondrodystrophic and non-chondrodystrophic breeds, including possible associations of some findings in relation to breed or sex, were considered as indicators that could be potentially useful in clinical veterinary practice for the assessment and possible prognosis of the status of patients with intervertebral disc disease. The current scientific literature on imaging diagnostics of TL-IVDD in dogs focuses also on some characteristics of CT in acute disc extrusion (Lim et al. 2010), or on the potential correlation of the degree of compression determined by using modern imaging methods with the severity of neurological impairment in dogs with TL-IVDD (Penning et al. 2006; Levine et al. 2009; Sakaguchi et al. 2023), or on the search for prognostic indicators with the possibility of using preoperative and postoperative (residual) spinal cord compression measurements using MRI to compare these measurements with the outcome of neurosurgical treatment in dogs following spinal decompression surgery for disc extrusion (Auffret et al. 2024). To date, however, no published scientific study has examined the relationship between the degree of severity of neurological impairment in dogs with TL-IVDD and the percentage of the narrowing of the spinal canal at the site of extrusion of the intervertebral disc material on CT scans in the transverse section of the vertebrae at the site of greatest compression of the spinal cord by extruded disc material (i.e., at the site of the greatest narrowing of the spinal canal by extruded disc material), which was the objective of this study.

In terms of clinical application of findings from the examination of TL-IVDD patients by tomographic imaging methods, the aim was to determine the relationship of the degree of severity of neurological impairment in dogs with TL-IVDD to the magnitude of spinal cord compression at the site of the greatest narrowing of the spinal canal by extruded disc material depending on the affected intervertebral disc area. Clarification of these very topical issues could contribute to current knowledge regarding the diagnosis and treatment of IVDD in dogs in clinical veterinary practice.

## Materials and Methods

A total of 78 dogs with TL-IVDD were included in the study that were examined and treated at the Department of Surgery and Orthopaedics, Small Animal Clinic, Faculty of Veterinary Medicine, University of Veterinary Sciences Brno between 1 October 2018 and 31 December 2022.

The patients under study were of both chondrodystrophic and non-chondrodystrophic breeds, represented by the Dachshund (n = 44; 56.41%), French Bulldog (n = 4; 5.13%), Maltese (n = 3; 3.85%), Bolognese (n = 2; 2.56%), Staffordshire Bull Terrier (n = 2; 2.56%), Jack Russell Terrier (n = 2; 2.56%), German Shepherd Dog (n = 2; 2.56%), Miniature Pinscher (n = 2; 2.56%), Löwchen (n = 1; 1.28%), Beagle (n = 1; 1.28%), Basset

Hound (n = 1; 1.28%), Cocker Spaniel (n = 1; 1.28%), Alpine Dachsbracke (n = 1; 1.28%), Coton de Tulear (n = 1; 1.28%), Slovakian Hound (n = 1; 1.28%), Patterdale Terrier (n = 1; 1.28 %), Chihuahua (n = 1; 1.28%), Border Collie (n = 1; 1.28%), West Highland White Terrier (n = 1; 1.28%), American Pit Bull Terrier (n = 1; 1.28%), Russian Tsvetnaya Bolonka (n = 1; 1.28%), Bernese Mountain Dog (n = 1; 1.28%), Papillon (n = 1; 1.28%), Dandie Dinmont Terrier (n = 1; 1.28%) and Yorkshire Terrier (n = 1; 1.28%).

The mean age of the TL-IVDD patients was 6.90 ± 2.94 years, with an age range from 2 to 15 years. Their sexes included 46 males (58.97%), of which 3 were neutered (3.85%), and 32 females (41.03%), of which 9 (11.54%) were neutered. Their mean body weight was 10.34 ± 8.35 kg with a range of 2.10 kg to 53.00 kg.

The diagnosis was based on signalment (breed, age, sex and weight), medical history, clinical examination, and neurological examination with localization of the lesion to the appropriate spinal cord segment (T3-L3). The patients were classified into one of the following 6 groups according to the degree of severity of neurological signs (Toombs and Bauer 1993) as follows: grade I (first episode of back pain and no motor deficit), grade II (recurrent pain and/or mild to moderate paraparesis), grade III (severe paraparesis), grade IV A (paraplegia with preserved deep pain), grade IV B (paraplegia, deep pain absent for less than 48 h), and grade IV C (paraplegia, deep pain absent for more than 48 h). In order to accurately localize the compressive lesion of the spinal cord (including the lateral localization of extruded disc material with relation to the spinal cord), a CT scan was performed under general anaesthesia on a 16-slice multidetector machine (LighSpeed 16 Slice, GE Medical Systems, Milwaukee, USA). Examinations were performed in the dorsal recumbency of the patient (to minimize motion artifacts) in a positioning cradle made of antidecubitus foam ensuring correct positioning during the CT examination and with fixation of the patient to the base using straps to ensure complete immobilization during the examination. The CT scan of the thoracolumbar spine was conducted with the following parameters: helical acquisition, 100 kV, automatically set mA value, slice width 1.25 mm, rotation time 1.0 s, pitch 0.938, low-frequency reconstruction algorithm (Standard). The Display Field of View (DFOV) was adjusted to the size of the patient being scanned to include at least the entire spine and the hypaxial and epaxial musculature. Retrospective reconstruction was performed in the high-frequency algorithm (bone) with a set slice width of 0.625 mm in some patients. In all patients (n = 78), a native CT scan of the affected spinal segment was taken. Where IVDD could not be identified on the native CT scan, the CT scan was repeated after caudal myelography (n = 22), and the contrast agent iomeprol (Iomeron 400, PNG Gerolymatos A.E.B.E., Kryoneri - Athens, Greece) was injected into the subarachnoid space at a dose of 0.35–0.45 ml/kg in the L5-L6 region after collection of a cerebrospinal fluid sample for laboratory examination.

A total of 78 dogs with TL-IVDD were evaluated to analyse individual indicators examined by CT in relation to the severity of neurological impairment in dogs with TL-IVDD, which were categorized according to the type of intervertebral disc degeneration (Hansen 1952) into two groups, namely the chondrodystrophic dog group (n = 55) and the non-chondrodystrophic dog group (n = 23), comparing some of the study aspects between the two groups with each other. The degree of spinal cord compression by extruded disc material in intervertebral disc extrusion in the TL region of the spine imaged with CT (native CT or CT myelography) was determined using a dedicated Advantage Workstation 4. The evaluation was performed on CT images in the soft tissue window (Spine, window width 200, window level 35) and the bone window (Bone, window width 300, window level 500) on transverse sections. All measurements on CT images of dogs with TL-IVDD included in this study were performed in Jivex (VISUS Health IT GmbH, Germany) used for visualization of Dicom format images which are stored in the PACS system (PostDICOM B.V., Herten, Netherlands) at our department.

The CT scans of the spinal canal in the studied patients were analysed as follows: for each patient, the intervertebral space affected by intervertebral disc extrusion and the percentage (extent of area) of the narrowing of the spinal canal by extruded disc at the site of the affected intervertebral space (determined at the site of the greatest compression of the spinal cord by extruded material of the intervertebral disc, and therefore the greatest narrowing of the spinal canal by extruded disc material) were recorded.

Compression of the thecal sac (i.e. spinal cord, spinal cord sheaths and cerebrospinal fluid appearing together on CT scan) by extruded intervertebral disc material was evaluated in JiveX in the transverse plane at a slice width of 1.25 mm. All measurements were performed in the "bone window – densit pelvis" (width 300.00, centre 45). In order to better assess the extent of compression within the spinal canal, the window width ranging between 20–917 (mean value 403.25) was used for patient examination. Magnification of 3.00 was set constant for all evaluated images. The area of extruded intervertebral disc material in the spinal canal (on the CT cross-section of the vertebra at the site of the greatest compression of the spinal cord by extruded intervertebral disc material, and thus the greatest narrowing of the spinal canal by extruded disc material) was defined in $mm^2$ to the nearest millimetre using the "polygon statistic measurement" function (Plate VII, Fig. 1).

Next, the area of the spinal canal in $mm^2$ (on the CT transverse section of the vertebra at the site of the greatest compression of the spinal cord by extruded material of the intervertebral disc, and thus the greatest narrowing of the spinal canal by extruded disc material) was defined using the "polygon statistic measurement" function (Plate VII, Fig. 2).

The percentage of the spinal canal narrowing (on the CT transverse section of the vertebra at the site of the greatest compression of the spinal cord by extruded material of the intervertebral disc, and therefore the greatest narrowing of the spinal canal by the material of the protruded disc) was calculated as follows: the area of the spinal canal (in $mm^2$) divided by the area of extruded material of the intervertebral disc (in $mm^2$).

The collected data were statistically evaluated. Statistical comparison of the severity of neurological signs and the percentage of spinal canal narrowing between dogs of chondrodystrophic breeds (n = 55) and dogs of non-chondrodystrophic breeds (n = 23), or between dogs of the Dachshund breed, other dogs of chondrodystrophic breeds and dogs of non-chondrodystrophic breeds, or between males and females, was performed using the least significant difference test.

TIBCO Statistica® software package v.14.0.0 (TIBCO Software Inc., USA) was used for statistical analysis. Data were tested for normality (Shapiro-Wilk test). Comparison of group differences was performed using the following methods: the test of differences between two proportions, analysis of variance (ANOVA), Kolmogorov-Smirnov test, Kruskal-Wallis test, Tukey test and Mann-Whitney U test. Statistical tests were evaluated with a statistical significance level of $P < 0.05$ or $P < 0.01$.

## Results

A total of 78 dogs with TL-IVDD (with herniation of a total of 89 discs due to extrusion of multiple discs simultaneously in some of the patients in the cohort) were evaluated, including 55 chondrodystrophic dogs and 23 non-chondrodystrophic dogs. In the 55 dogs of chondrodystrophic breeds, a total of 65 intervertebral discs affected by the extrusion of disc material into the spinal canal were evaluated because of multiple disc extrusions in the thoracolumbar spine in some of the patients included in the study; specifically, extrusion of 2 intervertebral discs simultaneously in 8 dogs and extrusion of 3 intervertebral discs simultaneously in 1 dog. Thus, in our cohort of 55 chondrodystrophic dogs, the relationship between the severity of neurological impairment in dogs with TL-IVDD and the degree of spinal cord compression at the site of the greatest narrowing of the spinal canal by extruded disc material was evaluated in CT scans in the transverse section of the vertebrae at the site of greatest spinal cord compression by extruded disc material (i.e. at the site of the greatest narrowing of the spinal canal by extruded disc material) in a total of 65 disc extrusions in the TL section of the spine. In 23 nonchondrodystrophic dogs, a total of 24 intervertebral discs affected by the extrusion of disc material into the spinal canal were evaluated because of the extrusion of two discs in one of the patients.

According to the severity of neurological signs due to TL-IVDD and the duration of clinical signs, 2 patients (2.56%) out of the 78 patients of both chondrodystrophic and non-chondrodystrophic breeds were classified as grade II impairment, 25 patients (32.05%) as grade III, 37 patients (47.44%) as grade IV A, 13 patients (16.67%) as grade IV B, and 1 patient (1.28%) as grade IV C based on the classification by the severity of neurological signs in dogs with TL-IVDD (Toombs and Bauer 1993).

The average size of the extruded area of the intervertebral disc material in the spinal canal in the patients studied was 16.29 ± 11.18 $mm^2$, with a minimum of 1.76 $mm^2$ and a maximum of 72.3 $mm^2$. The average area of the spinal canal including extruded disc material in the studied patients was 37.71 ± 18.06 $mm^2$, with a minimum of 9.21 $mm^2$ and a maximum of 100.98 $mm^2$. The mean percentage of spinal canal narrowing at the site of the greatest spinal cord compression by disc material in the studied patients was 43.19 ± 18.19%, with a minimum of 5.94% and a maximum of 89.02%.

By evaluating the percentage of spinal canal narrowing by extruded disc material at each intervertebral space, it was found that the herniation of disc material at the intervertebral disc space T9-T10 was diagnosed in one dog, in which the magnitude of spinal cord compression by extruded disc material was 23.36% of the spinal canal area. Extrusion of disc material at the T10-T11 intervertebral space was diagnosed in 5 dogs, in which the extruded disc material occupied on average 42.18 ± 10.50% of the spinal canal area. Extrusion of the intervertebral disc material at the T11-T12 space was diagnosed in 13 dogs, in which the extruded disc material occupied on average 48.35 ± 20.70% of the spinal canal area.

Extrusion of intervertebral disc material at the T12-T13 space was diagnosed in 24 dogs, in which the extruded material occupied on average 46.52 ± 17.30% of the spinal canal area. Disc material herniation at the T13-L1 space was diagnosed in 20 dogs, in which the extruded intervertebral disc material occupied on average 48.13 ± 20.60% of the spinal canal area. Extrusion of the intervertebral disc material at the L1-L2 space was diagnosed in 12 dogs, in which the extruded disc material occupied on average 36.29 ± 19.30% of the spinal canal area. Disc material herniation at the L2-L3 intervertebral space was diagnosed in 14 dogs, with the extruded material occupying an average of 33.06 ± 15.40% of the spinal canal area.

It was shown with a high statistical significance ($P = 0.001$) that chondrodystrophic breeds generally show a higher degree of neurological impairment (according to the classification into 6 grades according to the severity of neurological signs (Toombs and Bauer 1993) compared to non-chondrodystrophic breeds (Fig. 3). It can be concluded from Fig. 3 that dogs of chondrodystrophic breeds with intervertebral disc herniation due to TL-IVDD presented on average with grade IV A impairment (paraplegia with preserved deep pain), with the severity of neurological signs ranging from severe grade III paraparesis (as the "minimum severity of clinical signs") to grade IV C paraplegia with absence of deep pain for more than 48 h (as the "maximum severity of clinical signs"); whereas non-chondrodystrophic breeds of dogs with TL-IVDD presented clinically with a less severe degree of impairment on average than chondrodystrophic breeds of dogs, with rather severe grade III paraparesis, with the severity of neurological signs ranging from recurrent pain and/or mild to moderate grade II paraparesis (as the "minimum severity of clinical signs") to grade IV B paraplegia with absence of deep pain for less than 48 h (as the "maximum severity of clinical signs").

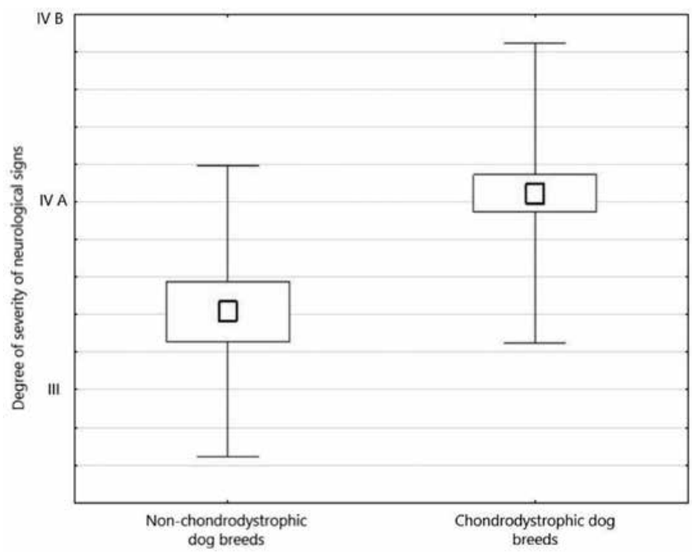


Fig. 3. Comparison of the severity of neurological signs due to intervertebral disc disease in chondrodystrophic and non-chondrodystrophic dog breeds. Dogs of chondrodystrophic breeds show a higher degree of neurological impairment compared to dogs of non-chondrodystrophic breeds, with highly significant difference ($P = 0.001$). Each boxplot represents the mean ± standard error of the mean.

In terms of other variables observed when comparing the group of chondrodystrophic dog breeds with the group of non-chondrodystrophic breeds, no significant difference was found in the percentage of spinal canal narrowing at the site of the greatest spinal cord compression by disc material ($P = 0.369$).

When comparing the severity of the degree of neurological signs as classified according to the severity of neurological signs into 6 grades (Toombs and Bauer 1993) among dogs of the Dachshund breed, dogs of the other chondrodystrophic breeds in the study population, and dogs of non-chondrodystrophic breeds, a highly significantly higher degree of severity of neurological impairment ($P = 0.001$) was observed in Dachshunds compared to dogs of non-chondrodystrophic breeds (Fig. 4). It can be concluded from Fig. 4 that Dachshunds with intervertebral disc herniation due to TL-IVDD presented on average with grade IV A impairment (paraplegia with preserved deep pain), same as dogs of other chondrodystrophic breeds, but differed in the severity of clinical signs with the severity of neurological signs ranging from severe grade III paraparesis (as the "minimum severity of clinical signs") to grade IV C paraplegia with absence of deep pain for more than 48 h (as the "maximum severity of clinical signs"); whereas the other chondrodystrophic breeds in our cohort of TL-IVDD patients presented with a prognostically slightly more favourable range of impairment from severe grade III paraparesis (as the "minimum severity of clinical signs") to grade IV B paraplegia with absent deep pain for less than 48 h (as the "maximum severity of clinical signs"), with paraplegia grade IV C with absence of pain for more than 48 h not diagnosed.

No difference was found in the severity of neurological signs between Dachshund dogs and dogs of other chondrodystrophic breeds in the patient group ($P = 0.534$) or between dogs of other chondrodystrophic breeds and dogs of non-chondrodystrophic breeds ($P = 0.068$) (Fig. 4). No significant difference was found between these groups (Dachshund vs other chondrodystrophic breeds, or other chondrodystrophic breeds vs non-chondrodystrophic breeds) in the percentage of spinal canal narrowing at the site of greatest spinal cord compression by extruded disc material ($P = 0.381$).

When comparing the percentage of spinal canal narrowing at the site of greatest spinal cord compression by extruded disc material between males and females in the study group of 78 both chondrodystrophic and non-chondrodystrophic dogs, females showed significantly higher percentage of spinal cord compression by extruded disc material, i.e. greater percentage of spinal canal narrowing ($P = 0.029$) compared to males (Fig. 5). No significant differences between males and females were found in the severity of neurological impairment ($P = 0.535$), mean HU extruded disc material density ($P = 0.743$) or mean HU spinal cord density ($P = 0.981$).

When neutered individuals in the cohort of 78 patients with TL-IVDD were considered in the statistical processing of the data, it was found that the highest percentage of spinal canal narrowing at the site of greatest spinal cord compression by disc material was found in neutered females compared to unneutered females ($P = 0.013$), and also compared to neutered males ($P = 0.029$) and unneutered males ($P = 0.001$), respectively (Fig. 6).

When comparing the percentage of spinal canal narrowing at the site of greatest spinal cord compression by disc material between intervertebral spaces in the study group of 78 dogs of both chondrodystrophic and non-chondrodystrophic breeds, it was shown that the percentage of spinal canal narrowing varied significantly between intervertebral spaces (Fig. 7). Specifically, the L2-L3 space (with the smallest percentage narrowing of the spinal canal and thus the smallest spinal cord compression by extruded disc material) compared to the T11-T12 ($P = 0.034$), T12-T13 ($P = 0.033$), and T13-L1 ($P = 0.022$) spaces which had the largest percentage narrowing of the spinal canal and thus the largest spinal cord compression by extruded disc material. Differences between the other intervertebral spaces were not significant.

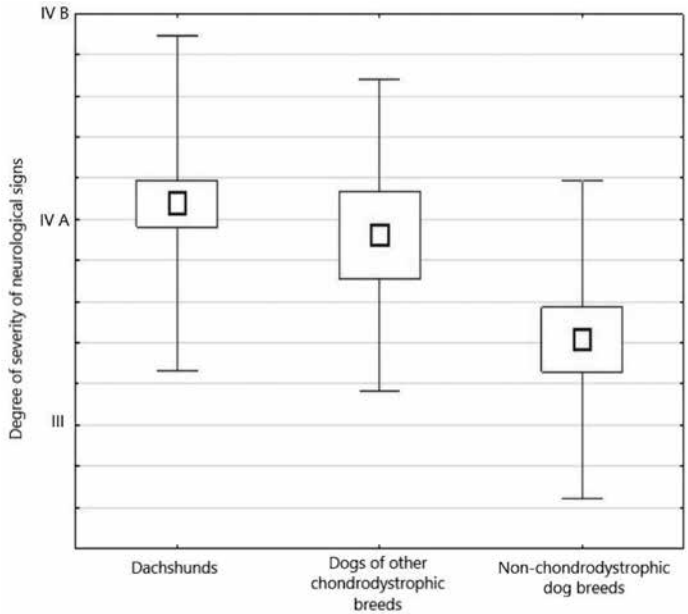

Fig. 4. Comparison of the severity of neurological signs due to intervertebral disc disease in Dachshunds, dogs of other chondrodystrophic breeds, and non-chondrodystrophic dog breeds. Dachshund dogs show a highly significantly higher degree of neurological impairment ($P = 0.001$) compared to non-chondrodystrophic dog breeds. Each boxplot represents the mean ± standard error of the mean.

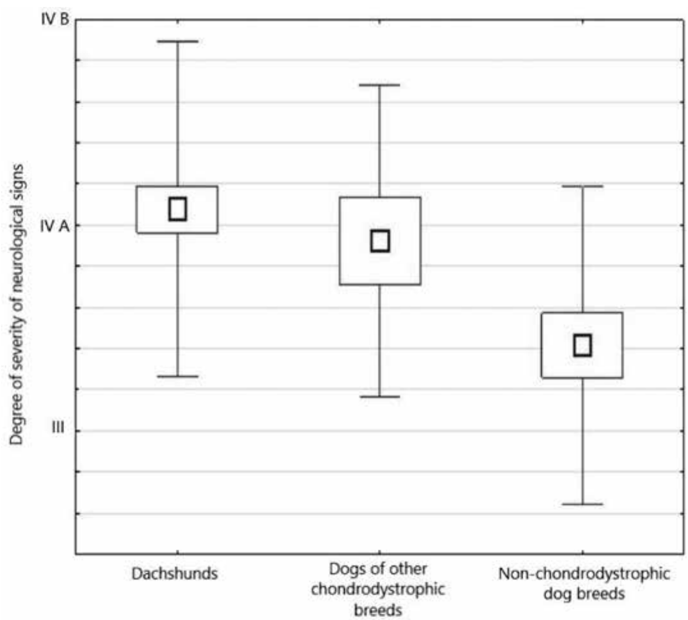

Fig. 5. Comparison of the percentage of spinal canal narrowing at the site of greatest spinal cord compression by disc material between males and females in the study population of both chondrodystrophic and non-chondrodystrophic dogs with thoracolumbar disc herniation. Females showed a significantly higher degree of severity of neurological impairment ($P = 0.029$) compared to males. Each boxplot represents the mean ± standard error of the mean.

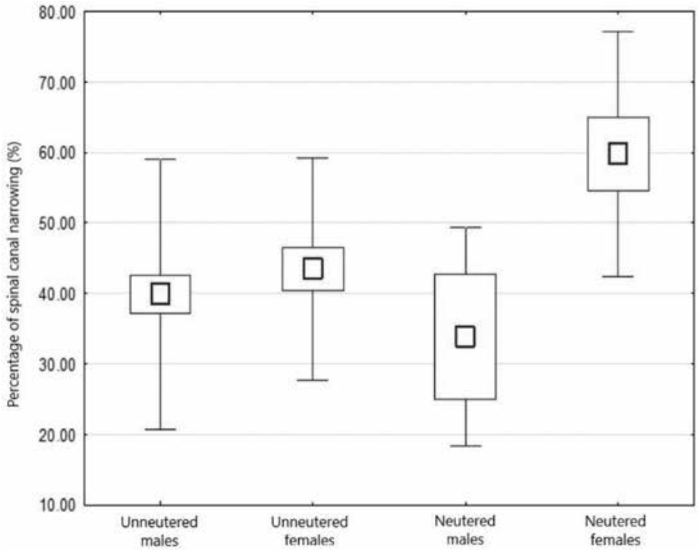


Fig. 6. Comparison of the percentage of spinal canal narrowing at the site of the greatest spinal cord compression by disc material in males and females (including differentiation of neutered individuals) in the study population of both chondrodystrophic and non-chondrodystrophic breeds with thoracolumbar disc herniation. The percentage of spinal canal narrowing is significantly higher in neutered females compared to unneutered females ($P = 0.013$) and also compared to neutered males ($P = 0.029$) and unneutered males ($P = 0.001$), respectively. Each boxplot represents the mean ± standard error of the mean.

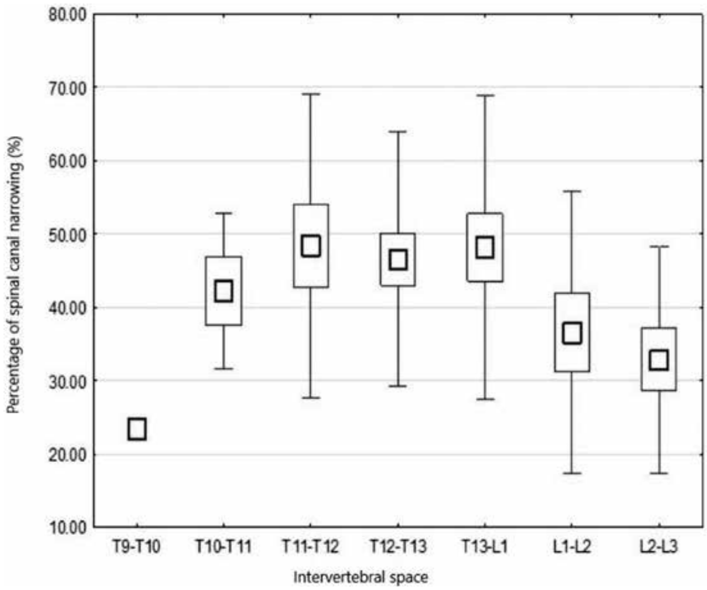


Fig. 7. Comparison of the percentage narrowing of the spinal canal at the site of greatest spinal cord compression by disc material between intervertebral spaces in the study population of both chondrodystrophic and non-chondrodystrophic breeds with thoracolumbar disc herniation. There was a significant difference in the percentage of spinal canal narrowing between the L2-L3 space and the T11-T12 ($P = 0.034$), T12-T13 ($P = 0.033$), and T13-L1 ($P = 0.022$) spaces, respectively. Each boxplot represents the mean ± standard error of the mean.

## Discussion

Testing the hypothesis that spinal cord compression by extruded disc material determined on CT transverse sections of the vertebrae at the site of the greatest narrowing of the spinal canal could be considered one of the relevant indicators of the severity of spinal cord injury is beneficial for veterinary practice. It is a relatively simple and rapid method to determine the magnitude of spinal cord compression during the preoperative diagnosis of TL-IVDD using CT as a modern imaging modality presently available in a large number of veterinary clinics specializing in the diagnosis and treatment of canine and feline diseases.

The reasoning behind the above hypothesis is partly based on a simplified parallel of the prognostic indicator in cases of TL vertebral fractures/luxations in dogs, where vertebral dislocation that reaches a limitation of 50% or more of the height of the spinal canal on the native radiograph in the laterolateral projection is the reason for unfavourable prognosis of the case before surgery. Similarly, the narrowing of the spinal canal by extruded disc material, measured as the percentage of disc material area at the site of greatest spinal cord compression, could be related to the severity (degree of impairment) of neurological findings in dogs with TL-IVDD.

We chose a relatively fast and simple method to measure the magnitude of spinal cord compression at the site of the greatest narrowing of the spinal canal by extruded material using CT on a CT cross-section (native CT or CT myelography) of the corresponding vertebral/intervertebral disc space with extrusion in the TL section of the spine, expressed as a percentage of the area of disc material extruded into the spinal canal. The reason for choosing this method to investigate the possibility of a relationship between the magnitude of spinal cord compression and the severity of neurological signs in dogs with intervertebral disc herniation due to TL-IVDD was the relatively good and ever increasing availability of CT scanners in veterinary clinics; at the same time, the aim was to eliminate inaccuracies resulting from the method of assessing the magnitude of spinal cord compression by extruded disc material based on the measured area of extruded disc material in $mm^2$; therefore, the percentage of the area of extruded disc material at the site of the greatest spinal cord compression was used (i.e. at the CT cross-section of the vertebra/intervertebral site affected by TL disc extrusion).

To date, it has been shown that the severity of clinical signs, and thus the impairment of spinal cord function and structure due to intervertebral disc herniation (Widmer and Thrall 2002), is influenced by factors such as the rate of compression force (the rate of the herniation of disc material into the spinal canal), the degree of compression, the duration of compression, and the ratio of spinal cord diameter to spinal canal diameter (Olsson 1958). The rate of the herniation of disc material into the spinal canal, and thus the high kinetic energy of the disc acting on the spinal cord, the volume of disc material herniated into the spinal canal, and the total length of the compressing material within the confined space of the spinal canal or multiple disc extrusions, often cause varying degrees of spinal cord oedema, and all of these factors subsequently affect the prognosis of the case (Nečas 1999a; Nečas 1999b). The structure of the disc material also plays a role in terms of the severity of the spinal cord injury, i.e. if it is a granular or pasty disc material, and also if the anulus fibrosus is erupted together with the degenerated disc nucleus, if the disc herniation is accompanied by bleeding from the vertebral sinuses, thereby increasing the volume of the compressing material, while the duration of spinal cord compression is also an important factor in the severity of neurological signs in dogs with TL-IVDD due to spinal cord injury (Nečas 1999a; Nečas 1999b).

In humans, the size of intervertebral disc herniation in relation to the size of the spinal canal in the lumbar spine has been shown to provide the best positive correlation with clinical findings (Thelander et al. 1994). A significantly positive correlation has also been found between improvement from sciatic pain and reduction in the size of individual lumbar disc herniations (Fagerlund et al. 1990). More recently, a weak positive correlation between the volume of extruded material at the site of herniation and the neurological severity of TL-IVDD type I has also been demonstrated, with the authors suggesting that the volume of extruded material is at least partially responsible for the observed severity of neurological findings in dogs with TL-IVDD type I (Sakaguchi et al. 2023). However, no correlation between the maximum transverse spinal cord compression ratio and neurological severity has yet been demonstrated. Previous studies based on MRI scans have suggested that the maximum transverse spinal cord compression ratio does not correlate with neurological severity in dogs with type I TL-IVDD (Penning et al. 2006; Levine et al. 2009). Meanwhile, the magnitude of spinal cord compression by disc material may have a greater influence on spinal cord function than the degree of local compression in the spinal cord (Levine et al. 2009). The pressure of the material in contact with the spinal cord is known to influence the severity of spinal cord injury and depends on the extent of the extradural lesion (Carlson et al. 1997; Carlson et al. 2003), as do a number of other factors, including the force of impact of extruded disc material on the spinal cord, acceleration and the degree of spinal cord dislocation (Carlson et al. 2003).

Our data show that the highest average percentage of spinal canal narrowing at the site of the greatest spinal cord compression by extruded disc material was observed at the T11-T12 space (48.35 ± 20.70%); followed by, in a descending order according to the magnitude of the percentage of spinal canal narrowing, intervertebral spaces T13-L1 (48.13 ± 20.60%), T12-T13 (46.52 ± 17.30%), T10-T11 (42.18 ± 10.50%), L1-L2 (36.29 ± 19.30%), and L2-L3 (33.06 ± 15.40%).

Based on a comparison of the relationship between the degree of severity of neurological impairment in dogs with TL-IVDD (Toombs and Bauer 1993) and the percentage of spinal cord compression at the site of greatest spinal canal narrowing by extruded disc material between a group of chondrodystrophic (n = 55) breeds and a group of non-chondrodystrophic (n = 23) dogs with TL-IVDD, we were able to demonstrate with high significance ($P = 0.001$) that dogs of chondrodystrophic breeds in the study cohort (n = 78) generally showed a higher/more severe degree of neurological impairment (Fig. 3) according to the classification into 6 grades based on the severity of neurological signs (grades I, II, III, IV A, IV B, and IV C [Toombs and Bauer 1993]) compared to dogs of non-chondrodystrophic breeds. Dogs of chondrodystrophic breeds with TL-IVDD presented on average with grade IV A impairment (paraplegia with preserved deep pain) and were simultaneously affected by minimum grade III and maximum IV C; whereas the average degree of impairment in non-chondrodystrophic breeds of dogs with TL-IVDD was more in the range of grade III (severe paraparesis) and they were simultaneously affected by minimum II and maximum grade IV B.

The more severe degree of neurological impairment in chondrodystrophic dog breeds may be related to the fact that the structure of the disc material also plays a role in the severity of the spinal cord injury (usually the harder granular disc material in chondrodystrophic breeds), but also that in chondrodystrophic dogs, the extrusion of the degenerated disc nucleus and part of the dorsal anulus fibrosus is usually involved. At the same time, during disc herniation, bleeding from extrusions of the damaged vertebral sinuses may occur, thus increasing the volume of the spinal cord compressing material. All of these factors may play a role in the less traumatic protrusion of a fibrinoid degenerated disc in non-chondrodystrophic dog breeds compared to spinal tissue. In addition, when comparing Dachshund dogs, dogs of other chondrodystrophic breeds, and dogs of non-chondrodystrophic breeds in the patient cohort under study, we demonstrated that Dachshunds (Fig. 4) presented with a highly significantly higher degree of severity of neurological impairment ($P = 0.001$) compared to dogs of non-chondrodystrophic breeds. This is probably also related to the fact that the degenerated granular disc material is harder in Dachshunds compared to disc material of non-chondrodystrophic dog breeds and that disc extrusion (i.e., acute and "explosive" extrusion of the degenerated nucleus with the dorsal part of the intervertebral disc annulus), is a more traumatic process for the spinal cord from a biomechanical point of view compared to intervertebral disc herniation in non-chondrodystrophic dog breeds, where the rupture of part of the concentric laminae of the anulus fibrosus usually results only in partial dislocation of the nucleus and only partial herniation of the disc into the spinal canal, which is a less traumatic cause of spinal cord compression from a mechanical point of view. The TL-IVDD Dachshunds presented on average with grade IV A impairment (paraplegia with preserved deep pain sensation) same as the other chondrodystrophic breeds; and that they were simultaneously affected by minimum grade III and by maximum grade IV C whereas the other chondrodystrophic breeds were affected by minimum grade III and by maximum grade IV B (thus, no grade IV C was detected). To our knowledge, these findings have not been published in the scientific literature to date.

Our study in dogs affected by TL-IVDD also resulted in new findings regarding the relationship of sex to some of the observed variables. Comparing the percentage of spinal canal narrowing at the site of greatest spinal cord compression by extruded disc material between males and females in a study group of 78 patients of both chondrodystrophic and non-chondrodystrophic breeds, it was demonstrated that females showed significantly higher percentage of spinal cord compression by extruded disc material, i.e. greater percentage of spinal canal narrowing ($P = 0.029$) compared to males (Fig. 5). When neutered individuals in the cohort of 78 patients with TL-IVDD were considered in the statistical data processing, it was found that the highest percentage of narrowing of the spinal canal at the site of greatest spinal cord compression by disc material was detected in neutered females compared to unneutered females ($P = 0.013$), and also compared to neutered males ($P = 0.029$) and unneutered males ($P = 0.001$), respectively (Fig. 6). To our knowledge, these findings have not been published in the scientific literature to date, either. However, whether these findings are in any way related to the finding that the risk of disc extrusion in males > risk in neutered females > risk in females, which is usually attributed to the effect of oestrogen acting against disc degeneration (Priester 1976), is unknown, and further studies will be needed to clarify similar questions.

A novel finding that emerged from the results of our study when comparing the percentage of spinal canal narrowing at the site of greatest spinal cord compression by disc material between the intervertebral spaces in 78 dogs of both chondrodystrophic and non-chondrodystrophic breeds was that the magnitude of percentage spinal canal narrowing differed significantly between the intervertebral spaces (Fig. 7). Specifically, the L2-L3 space with the smallest percentage narrowing of the spinal canal and thus the smallest spinal cord compression by extruded disc compared to the T11-T12 ($P = 0.034$), T12-T13 ($P = 0.033$), and T13-L1 ($P = 0.022$) spaces with the largest percentage narrowing of the spinal canal and thus the largest spinal cord compression by extruded disc material. Differences between the other intervertebral spaces were not significant. As previously published, the T12-T13, T13-L1, and T11-T12 spaces are the three most frequently affected areas in terms of the frequency of intervertebral disc herniation in the thoracolumbar spine in chodrodystrophic dog breeds, with T12-T13 space being most often affected by disc extrusion (Toombs and Bauer 1993; Bray and Burbridge 1998a; Bray and Burbridge 1998b; Nečas 1999a; Nečas 1999b; Toombs and Waters 2003; Sharp and Wheeler 2005). However, whether this fact has any relation to the extent of narrowing of the spinal canal by the extruded disc in the respective intervertebral spaces is not yet known and may be the subject of further investigation of characteristics related to TL-IVDD in dogs.

In conclusion, CT has an irreplaceable place in the diagnosis of thoracolumbar intervertebral disc extrusion in dogs. In our cohort of patients with TL-IVDD, we were able to newly demonstrate some characteristics of CT in relation to the neurological severity of signs in dogs with disc extrusion, which, to our knowledge, have not been previously published. Future follow-up studies may help to clarify other possible clinical associations with some of the findings of this study in dogs with TL-IVDD based on their CT evaluations.

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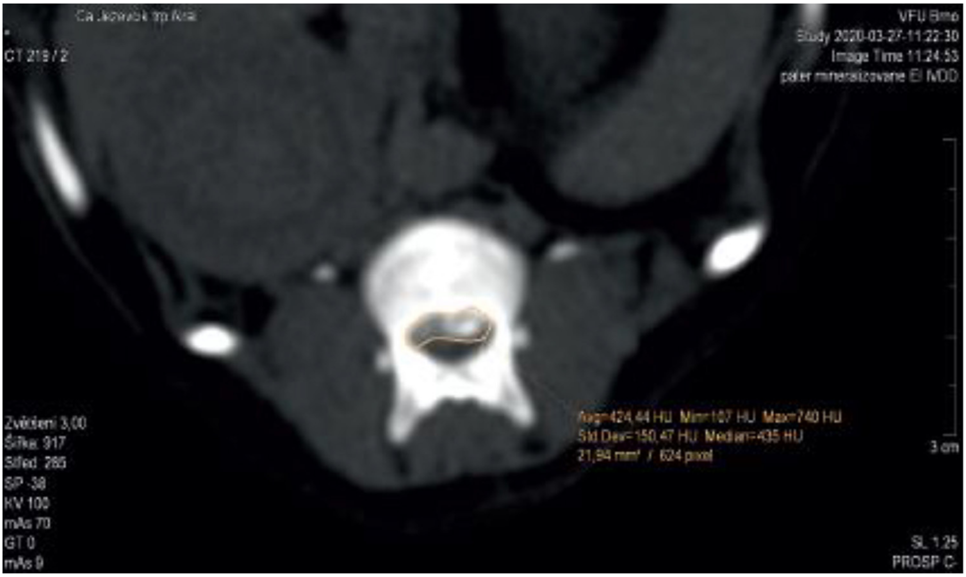


Fig. 1. Computed tomography scan of the spine in the transverse plane in a 5-year-old female Miniature Dachshund with delineation of the area of extruded intervertebral disc material in the spinal canal at T13-L1 using the “polygon statistic measurement” function in JiveX.


Fig. 2. Computed tomography scan of the spine in the transverse plane in a 5-year-old female Miniature Dachshund with delineation of the spinal canal area at T13-L1 at the site of greatest spinal cord compression by extruded intervertebral disc material (and greatest spinal canal narrowing) using the “polygon statistic measurement” function in JiveX.