






## CONGENITAL VERTEBRAL MALFORMATIONS AND THEIR ASSOCIATION WITH INTERVERTEBRAL DISC DISEASE IN FRENCH BULLDOGS: A RETROSPECTIVE COMPUTED TOMOGRAPHY STUDY

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Congenital vertebral malformations (CVM) are common in French Bulldogs and may contribute to neurological dysfunction and intervertebral disc disease (IVDD). This retrospective study evaluated the prevalence, types, and distribution of CVM using computed tomography (CT) and assessed their association with IVDD and neurological signs. CT studies of the spine (C7–S1) from 62 French Bulldogs examined between February 2020 and February 2025 were reviewed. Dogs ranged from 1.7 to 12 years of age (mean  $\pm$  SD, 5.0  $\pm$  2.4 years), and 50 (80.6%) exhibited neurological signs. Congenital vertebral malformations were identified in 57 dogs (91.9%), with hemivertebrae present in all affected dogs, transitional vertebrae in 35.1%, and articular process dysplasia in 1.8%. Thoracic hemivertebrae were detected in all dogs with CVM, most frequently as multiple lesions (94.7%), often associated with angular spinal deviations, predominantly kyphoscoliosis. Intervertebral disc disease was diagnosed in 58 dogs (93.5%), most commonly lumbar or lumbosacral, and was multiple in 86.2% of cases. Most dogs with CVM also had IVDD (93.0%), whereas only five dogs had IVDD without CVM. Significant associations were found between CVM and neurological signs ( $\chi^2 = 66.24$ ,  $p < 0.05$ ), CVM and IVDD ( $\chi^2 = 113.85$ ,  $p < 0.05$ ), and IVDD and neurological signs ( $\chi^2 = 128.58$ ,  $p < 0.05$ ). No significant associations were observed between sex, CVM type or number, and clinical signs. These findings demonstrate a high prevalence of CVM and IVDD in French Bulldogs and support the role of CT in comprehensive spinal assessment.

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**Keywords:** computed tomography, congenital vertebral malformations; French Bulldog; hemivertebrae; intervertebral disc disease

## INTRODUCTION

Increasing popularity of small brachycephalic dog breeds such as the Bulldog, French Bulldog and Pug has led to considerable concern about the welfare of these breeds [1,2]. In particular, the French Bulldog has experienced a substantial increase in popularity over the past decade, consistently ranking among the top ten breeds in the United States [3] and Canada [4] since 2015, with similar trends observed across Europe. Selective inbreeding has produced the brachycephalic and chondrodystrophic conformation characteristic of French Bulldogs, which contributes to a high incidence of various disorders, including spinal disorders [5]. One notable group of spinal disorders particularly associated with French Bulldogs and other small brachycephalic breeds is congenital vertebral malformations (CVM) [6,7].

Although the terminology used to describe these malformations remains disputed, they are typically classified into two main categories: defects in vertebral segmentation (block vertebrae) and defects in vertebral body formation (hemivertebrae). Other anomalies include transitional vertebrae, hypoplasia or aplasia of the articular processes, and spina bifida [8,9]. Hemivertebrae are defined as vertebral body formation defects characterized by partial absence of the vertebral body [7]. Block vertebrae are defined as segmentation defects between two adjacent vertebral bodies, resulting in the absence of the intervertebral space [8]. Transitional vertebrae are located at the junction between two regions of the vertebral column and exhibit variable morphology, possessing characteristics of both adjacent vertebral types. They may also lead to variations in the number of vertebrae within a specific spinal segment and can occur as cervicothoracic, thoracolumbar, or lumbosacral [8,10]. Articular process dysplasia is characterized by a complete (aplasia) or partial (hypoplasia) absence of one or more articular processes of the vertebrae [6]. Spina bifida is defined as incomplete closure of the vertebral arches during embryonic development, resulting in a cleft through the spinous process of the vertebra [8].

Congenital vertebral malformations may occur as isolated or as multiple anomalies in a single dog, most frequently affecting the thoracic spine [11–13]. Several studies have reported a high prevalence (ranging from 80.7% to 87.7%) of congenital vertebral malformations affecting the thoracic spine of small brachycephalic breeds [11,14,15–18]. In general, when neurological deficits are absent, these malformations are regarded as incidental findings on radiographic evaluation [8,11,13]. However, they can occasionally interfere with the biomechanics of the vertebral column and serve as the underlying cause of neurological dysfunction [7,19]. In case of clinical manifestation, signs often include progressive myelopathy due to vertebral canal stenosis and/or vertebral instability associated with angular spinal deviations such as kyphosis and scoliosis. Spinal cord compression may lead to symptoms such as ataxia and hind

limb atrophy, paraparesis or paraplegia, loss of spinal reflexes, and incontinence. Although vertebral anomalies may be evident at birth, clinical signs typically develop later in life [8,11,15,20]. Therefore, it is important to determine which cases require further investigation, differentiating clinically relevant from irrelevant CVM, in order to establish an accurate diagnosis and initiate appropriate treatment [7].

Radiography is the most commonly used diagnostic tool for detecting congenital vertebral malformations in dogs. Computed tomography (CT) and magnetic resonance imaging (MRI) are used less frequently but provide much more precise findings [7,8]. Although no official screening program for CVM in dogs currently exists, some organizations have introduced basic radiographic protocols [13]. Conventional radiography has shown limitations in detecting, classifying, and evaluating the severity of certain vertebral malformations, compared to CT, which is efficient in this regard and offers more detailed assessment of complex skeletal structures [21,22]. As such, CT is considered the most reliable imaging modality for vertebral column assessment and holds great potential for establishing accurate screening protocols in future selective breeding programs [23–25]. However, it can be argued that the main disadvantage of CT is that it generally delivers substantially higher radiation doses to patients [26]. Furthermore, subjecting patients to a CT scan also requires mandatory anesthesia [27].

In addition to CVM, intervertebral disc disease (IVDD) is another significant cause of spinal cord compression and neurological dysfunction in French Bulldogs. Due to their chondrodystrophic nature, they are predisposed to Hansen type I intervertebral disc degeneration (IVD extrusion) [28,29]. IVD extrusion is characterized by chondroid degeneration of the nucleus pulposus and sudden herniation of the transformed (often mineralized) nuclear material through all layers of the ruptured annulus fibrosus into the vertebral canal and/or intervertebral foramen [28,30]. Chondrodystrophic dogs can also develop Hansen type II intervertebral disc degeneration (IVD protrusion) [31,32]. IVD protrusion is characterized by fibroid degeneration of the nucleus pulposus with focal, often smooth, and round herniation of the nuclear material and annulus fibrosus into the vertebral canal and/or intervertebral foramen [28,30]. Considering that CVM and IVDD may coexist and present with similar signs, distinguishing between them and assessing their potential clinical relevance is essential for establishing an accurate diagnosis and planning appropriate treatment [33]. Particularly useful in this context, especially when planning surgery, are the advanced imaging modalities, such as CT and MRI [29,34]. The aim of this study is to assess the prevalence, types, and anatomical distribution of congenital vertebral malformations in French Bulldogs using computed tomography, and to investigate their potential association with intervertebral disc disease.

## **MATERIALS AND METHODS**

This retrospective study included archived findings from 62 French Bulldogs that underwent CT imaging at the Department of Radiology, Physical Therapy and

Ultrasound Diagnostics, Faculty of Veterinary Medicine in Zagreb between February 2020 and February 2025. Inclusion criteria required complete CT studies of the thoracic and lumbar spine, specifically from the last cervical vertebra (C7) to the first sacral vertebra (S1). Dogs were included regardless of the clinical indication for CT; some were presented for neurological evaluation (described as symptomatic or with clinical signs), while others were presented for unrelated pathologies (described as asymptomatic or without clinical signs). The research was conducted in compliance with all relevant national regulations and institutional policies regarding the care and use of animals (The Committee for Ethics in Veterinary Medicine, Faculty of Veterinary Medicine, University of Zagreb (Class: 640-01/25-02/11; Ref. No: 251-61-01/139-25-36), issued September 17th 2025). Informed consent has been obtained for client-owned animals included in this study.

Data collected from medical records included age, sex and clinical status. The dogs were categorized based on the presence or absence of neurological signs indicating spinal cord dysfunction, such as gait abnormalities accompanied by spinal pain, ataxia, paraparesis, proprioceptive deficits, and incontinence. Additionally, the presence and type of CVM, and the presence of IVDD were documented based on CT findings.

CT imaging was performed using a SIEMENS SOMATOM go.Now 32 (Siemens, Germany), with patients positioned in sternal or dorsal recumbency. Patients admitted with suspected spinal pathology were positioned in dorsal recumbency, while patients with any other indication for CT were positioned in sternal recumbency. Images were acquired in the transverse plane and reconstructed in the sagittal and dorsal planes using high-resolution bone and soft tissue algorithms. Slice thickness and spacing were set to 0.8 – 2.0 mm depending on the patient's reason for imaging (0.8 mm for neurological evaluation; 1 – 2 mm for unrelated pathologies). CT scans were evaluated at the time of diagnosis by at least one board-certified radiologist.

CVM were identified and classified into five groups: hemivertebrae, block vertebrae, transitional vertebrae, articular process dysplasia, and spina bifida.

For each dog, the number and anatomical location of CVM were recorded. Hemivertebrae were further categorized as single or multiple, contiguous or non-contiguous (separated), and thoracic or lumbar in location. Transitional vertebrae were classified based on their anatomical location and number (single, multiple). The presence of spinal deviation (kyphosis, scoliosis, kyphoscoliosis, and lordosis) was also documented. IVDDs were classified based on their number and anatomical location.

### **Statistical analysis**

Pearson's chi square test of independence was performed for contingency tables that fulfilled the chi-square assumption for cell counts  $n > 5$ . For analysis that included cells  $n < 5$ , a simulation analysis was conducted with  $n = 10,000$  (Monte Carlo simulation). The significance level was set at  $p < 0.05$ . Power analysis was performed for each analysis with corresponding degrees of freedom (G\*Power, version 3.1.9.2,

Universität Kiel, Germany). The level of association for the positive responses of each question and the respective response-categories was assessed with Cramér's V value and the corresponding degrees of freedom (df). All responses were expressed as counts (n) and percentages (%).

## RESULTS

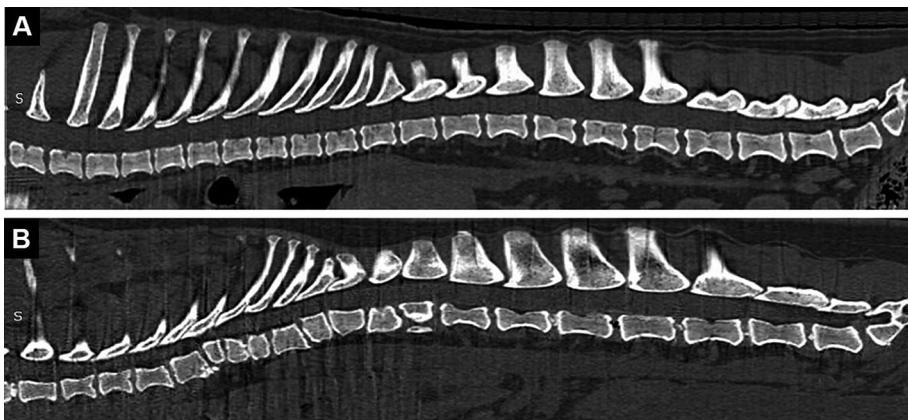
A total of 62 French Bulldogs were included in the study group. The group comprised of 44 males and 18 females, aged between 1.7 and 12 years (mean,  $5.0 \pm 2.4$ ; median, 4.0) and weighing between 8.2 and 18 kg (mean,  $13.0 \pm 2.6$ ; median, 12.7).

Neurological signs were present in 50 dogs (80.6%).

Congenital vertebral malformations (CVM) were identified in 57 dogs (91.9%). These included hemivertebrae in all 57 dogs (100%), transitional vertebrae in 20 (35.1%) and articular process dysplasia in one dog (1.8%). No cases of block vertebrae or spina bifida were detected. Among the 57 dogs with CVM, 37 (64.9%) had a single type of CVM (hemivertebrae), 19 (33.3%) had two types (hemivertebrae and transitional vertebrae) and only one dog (1.8%) had three different types (hemivertebrae, a transitional vertebra and articular process dysplasia).

Neurological signs were observed in 45 of the 57 dogs with CVM (78.9%). Of the 50 dogs with clinical signs, only five (10%) were free of CVM.

Thoracic hemivertebrae were present in all 57 dogs with CVM (100%), while three dogs (5.3%) also had lumbar hemivertebrae. A single hemivertebra was found in only 5.3% ( $n = 3$ ) of the dogs with hemivertebrae, each located on a different thoracic vertebra (T7, T8, and T9). The majority of dogs (54/57, 94.7%) had multiple hemivertebrae (Fig. 1), which were either contiguous (33/54, 61.1%) or distributed separately along the spine (21/54, 38.9%).



**Figure 1.** Sagittal CT images of the thoracolumbar spine in two canine patients. **A:** Four-year-old male Shih Tzu with normal vertebral alignment and morphology. **B:** Three-year-old female French Bulldog demonstrating multiple thoracic hemivertebrae at T6, T7, T8, T10, T12 and T13, thoracic kyphosis, as well as C7-T1, L2-L3, L4-L5, L5-L6 and L6-L7 intervertebral disc calcification.

The most common anatomical location for hemivertebrae was T5–T9 (Table 1). Angular deviation of the spine was detected in more than two-thirds of the dogs with hemivertebrae (40/57, 70.2%), most commonly presenting as kyphoscoliosis (27/40, 67.5%), followed by kyphosis (10/40, 25%), and scoliosis (3/40, 7.5%). Lordosis was not observed in any dog in this study.

**Table 1.** Frequency distribution of hemivertebrae across spinal segments in all 57 affected dogs.

| Spinal segment  | Affected dogs |
|-----------------|---------------|
| <b>Thoracic</b> |               |
| T1              | 2             |
| T2              | 6             |
| T3              | 9             |
| T4              | 16            |
| T5              | 33            |
| T6              | 38            |
| T7              | 42            |
| T8              | 46            |
| T9              | 41            |
| T10             | 25            |
| T11             | 21            |
| T12             | 13            |
| T13             | 7             |
| <b>Lumbar</b>   |               |
| L1              | 0             |
| L2              | 0             |
| L3              | 0             |
| L4              | 0             |
| L5              | 0             |
| L6              | 0             |
| L7              | 3             |

Transitional vertebrae were identified in 20 of the 57 dogs with CVM (35.1%). Only two of these dogs (10%) had two transitional vertebrae simultaneously; one had thoracolumbar and lumbosacral, and the other had cervicothoracic and thoracolumbar

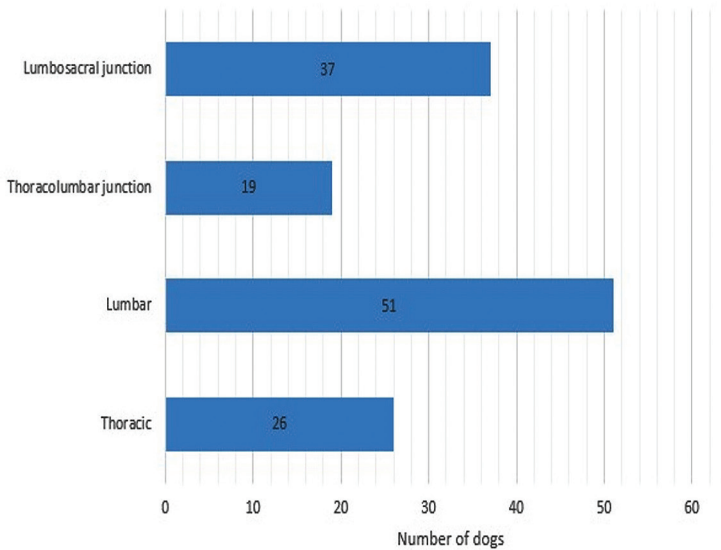
transitional vertebrae. Most were thoracolumbar (14/22, 63.7%), followed by cervicothoracic (5/22, 22.7%), with lumbosacral transitional vertebrae being the least frequent (3/22, 13.6%) (Table 2).

**Table 2.** Frequency distribution of transitional vertebrae across spinal segments in all 20 affected dogs.

| Spinal segment  | Affected dogs |
|-----------------|---------------|
| Cervicothoracic | 5             |
| Thoracolumbar   | 14            |
| Lumbosacral     | 3             |

Articular process dysplasia was detected in one dog, presenting as multiple involving two vertebrae (hypoplasia of the caudal articular facets of T11 and T12).

Intervertebral disc disease (IVDD) was found in 58 out of 62 dogs (93.5%). Of these, 84.5% (n = 49) showed neurological signs. Multiple IVDDs were present in 50 of the affected dogs (86.2%). Lumbar disc herniations were the most common (51/58, 87.9%), followed by lumbosacral (37/58, 63.8%), thoracic (26/58, 44.8%), and thoracolumbar herniations (19/58, 32.8%) (Fig. 2).



**Figure 2.** Histogram illustrating the anatomical distribution of intervertebral disc disease across spinal segments in affected dogs.

The most frequently affected locations for IVDD were L2–L3 (n = 39), L7–S1 (n = 37), and L3 – L4 (n = 32) (Table 3). The majority of dogs with CVM also had IVDD (53/57, 93%), whereas only five dogs (8.1%) had IVDD without CVM.

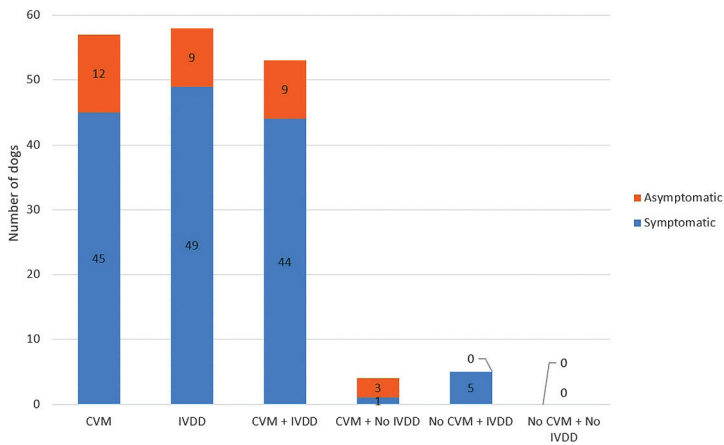
**Table 3.** Frequency distribution of IVDD across spinal segments in all 58 affected dogs.

| Spinal segment | Affected dogs |
|----------------|---------------|
| C7-T1          | 0             |
| T1-T2          | 0             |
| T2-T3          | 2             |
| T3-T4          | 2             |
| T4-T5          | 2             |
| T5-T6          | 3             |
| T6-T7          | 5             |
| T7-T8          | 2             |
| T8-T9          | 5             |
| T9-T10         | 7             |
| T10-T11        | 7             |
| T11-T12        | 9             |
| T12-T13        | 12            |
| T13-L1         | 19            |
| L1-L2          | 23            |
| L2-L3          | 39            |
| L3-L4          | 32            |
| L4-L5          | 24            |
| L5-L6          | 18            |
| L6-L7          | 13            |
| L7-S1          | 37            |

Despite the considerably higher percentage of males compared to females in all examined categories, statistical analysis revealed no significant association between sex and presence of CVM ( $\chi^2 = 0.215$ ,  $p = 1.0$ ). There was no significant association between the number of CVM types and the presence of clinical signs ( $p = 0.742$ ); specifically, 75.7% of dogs with one CVM type and 85% of dogs with multiple CVM types were symptomatic. There was no significant difference in the occurrence of neurological signs between dogs with hemivertebrae (78.9% symptomatic) and those

with transitional vertebrae (85% symptomatic) ( $p = 0.845$ ). Similarly, the number of hemivertebrae did not significantly influence the clinical presentation ( $p = 0.845$ ); clinical signs were observed in 66.7% of dogs with a single hemivertebra and in 79.6% of those with multiple hemivertebrae.

Statistical significance was confirmed in assessing associations between CVM, IVDD, and the presence of clinical signs (Fig. 3). A significant association was found between CVM and clinical signs ( $\chi^2 = 66.24$ ,  $df = 2$ ,  $p < 0.05$ ). A strong statistical association was also found between CVM and IVDD ( $\chi^2 = 113.85$ ,  $df = 2$ ,  $p < 0.05$ ). Similarly, the presence of IVDD was significantly associated with clinical signs ( $\chi^2 = 128.58$ ,  $df = 2$ ,  $p < 0.05$ ).



**Figure 3.** Histogram illustrating the distribution of CVM and/or IVDD in symptomatic and asymptomatic dogs.

## DISCUSSION

The results of the study demonstrated a very high prevalence of congenital vertebral malformations (CVM) affecting 57 French bulldogs (92%). This prevalence exceeds the 80–88% range reported in previous radiographic studies of neurologically normal brachycephalic breeds, including French Bulldogs, English Bulldogs, and Pugs [11,13,14]. The higher detection rate in the present study is likely explained by the greater sensitivity of computed tomography.

Brocal *et al.* [23] demonstrated that CT detects more complex and subtle bony lesions than conventional radiography, while Corlat *et al.* [24] showed that CT offers greater diagnostic sensitivity with a more comprehensive evaluation of vertebral morphology and spinal curvature, especially when using 3D reconstruction. Similar to several previous studies, in the spectrum of vertebral lesions hemivertebrae predominated, usually occurring in multiples and arranged continuously along the thoracic spine [8,13,14]. This improved sensitivity is particularly relevant for vertebral malformations

that are radiographically undetectable or poorly visualized, such as articular process dysplasia, spina bifida and subtle hemivertebrae. Nearly four out of five dogs in our study exhibited neurological signs. This suggests that dogs with CVM could be significantly more likely to develop neurological deficits than those without CVM, which is contrary to the long-standing assumption that most CVM are incidental radiographic findings [6,8,12]. However, this interpretation should be viewed with caution, as our sample was relatively small and most dogs were admitted for neurological evaluation. IVDD was even more common (94%) and also strongly associated with the occurrence of neurological signs. Particularly important is that 93% of dogs with CVM also had at least one intervertebral disc herniation, confirming the close association between CVM and IVDD, proposed and quantified by Aikawa et al. [15] and De Rycke and Saunders [19]. These results contribute to the scientific understanding that CVM and IVDD form a complex, multifactorial spectrum of spinal diseases in French Bulldogs.

Although hemivertebrae are common, their clinical impact is heterogeneous. In our study, similar to the findings of Schlensker and Distl [13] and Ryan et al. [14], neither the sex of the dogs nor the number of hemivertebrae were prognostic factors for outcome or the likelihood of neurological dysfunction. Rather, it seems that the determining factors are the vertebral configuration and spinal curvature. More than two-thirds of the dogs with hemivertebrae in this study showed kyphosis or kyphoscoliosis, and these deformities predominated in clinically symptomatic dogs. This is consistent with the surgical cases of Moissonnier et al. [11] and the MRI study of Faller et al. [17] that associated pronounced curvature with accelerated intervertebral disc degeneration. The angular magnitude of a spinal curvature is usually quantified using the Cobb angle which is defined as the angle of the most tilted vertebra [35]. Notably, dogs with a Cobb angle  $>35^\circ$  are argued to have significantly higher risk for developing neurological signs [36]. Although the degree of spinal kyphosis was not measured in our study, it can be hypothesized that severe angular deviation of the spine reduces the width of the spinal canal, impairs load distribution, and predisposes to spinal cord compression or instability. A recent prospective study suggests that thoracic kyphosis may cause changes in hindlimb kinematics even before the onset of overt neurological deficits, supporting the hypothesis that CVM may subclinically disrupt spinal biomechanics [37]. Therefore, recognition of such “high-risk” malformations on CT may have a direct prognostic value.

IVDD was detected in almost every dog and was usually multifocal. The lumbar segment of the spine was most affected, an anatomical predisposition first described by Aikawa et al. [15]. Our data are consistent with the study by Brisson [28], who emphasized that in chondrodystrophic breeds there is a tendency for intervertebral disc herniation at a younger age than in non-chondrodystrophic breeds. A recent surgical study indicates that 46% of French Bulldogs with thoracolumbar disc extrusions regained deep pain perception within one month after successful decompression surgery, but only 19% were independently ambulatory [38]. Another long-term follow-up study reveals that approximately half of the French Bulldogs redeveloped clinical signs after

successful surgery [39], highlighting the chronic, multifocal nature of IVDD in this breed. Considering these reports, combined with the strong association of IVDD with clinical signs in our study, it is reasonable to consider IVDD as the immediate cause of the neurological deficit, with CVM acting as a predisposing or aggravating factor.

Our study found a high overlap of dogs with CVM and IVDD, and both conditions were strongly associated with occurrence of neurological signs. This comorbidity between CVM and IVDD plays an important role in identifying the main cause of neurological deficits and for planning treatment. Faller et al. [17] state that pronounced focal kyphoscoliosis or kyphoscoliosis contributes to early intervertebral disc degeneration adjacent to the site of spinal deviation. In dogs with thoracic kyphosis, disc herniation rarely occurs at the apex of the curve, but usually cranial or caudal to the deviation [15], which our study also confirms. Genetics also do not favor French Bulldogs. They carry the FGF4 retrogene on CFA12, which is responsible for chondrodystrophy and early intervertebral disc degeneration, especially Hansen type I IVDD [40]. Furthermore, Mansour et al. [41] suggest that a frameshift mutation in the *Disbevelled 2 (DVL2)* gene, associated with the “screw-tail” phenotype in French Bulldogs, also predisposes them to thoracic vertebral malformations. Therefore, the CVM-IVDD relationship should be viewed as biomechanically synergistic, not coincidental, and clinicians must consider both in symptomatic French Bulldogs. A dog may have both conditions simultaneously, but identifying the primary cause of spinal cord compression requires advanced imaging techniques, such as CT or MRI.

Numerous studies have shown that CT is superior to radiography for detecting and classifying CVM, improves the objective assessment of spinal deviation, and allows easy recognition of subtle dysplasia of articular processes or transitional vertebrae [18,23,24]. CT eliminates superimposition and allows for multiplanar reconstructions, making it ideal for evaluating complex skeletal structures [21,22]. This was evident in our study, where CT detected rare lesions such as articular process dysplasia in a single dog – a finding that would likely be missed with conventional radiography. Non-contrast CT is also sensitive for detecting calcified disc extrusions [33], which was confirmed in our case. However, for detecting non-mineralized protrusions or changes in the spinal cord, MRI is a complementary method [30,33]. In addition to non-mineralized disc pathology, MRI is superior in detecting abnormalities in other soft tissue structures, such as ligamentous injuries, spinal cord or nerve root lesions, epidural processes (including hematoma or abscess), and non-calcified neoplastic or inflammatory conditions [42–44]. Accordingly, this highlights that CT should be the first-choice method for structural evaluation of the spinal column in brachycephalic breeds with suspected CVM, while MRI should be used as an additional method when there is suspicion of pathological changes in the soft tissues or when neurological signs are strongly expressed.

Considering that eight out of ten French Bulldogs in our study exhibited neurological symptoms, it could be hypothesized that CVM contribute to this serious welfare issue in this breed. Although the study indicates a high risk for neurological symptoms,

it is reasonable to suggest that the cause and severity of these symptoms depend on the combination of CVM configuration, spinal deformity, and the presence of IVDD. Waters [2] called for urgent action to overcome health disorders related to extreme brachycephalic conformation. Estimates of moderate heritability for thoracic hemivertebrae in French Bulldogs ( $\approx 0.36$ ) [16] indicate that selective breeding could reduce the prevalence, even if complete eradication is unrealistic. Existing radiographic screening schemes have limited sensitivity [13,16,24]. Therefore, as our findings suggest, it is advisable to introduce an optimized low-dose CT protocol to evaluate the spinal cord, as first proposed by Drees et al. [45]. Our study emphasizes the need for stricter breeding regulations to reduce the occurrence of extreme conformations that predispose to CVM and IVDD. Excluding from breeding dogs with multiple hemivertebrae or severe spinal curvature (kyphosis/kyphoscoliosis), combined with genetic testing for alleles associated with risk of IVDD [46], could represent a concrete approach to promoting spinal health. Veterinary clinicians should take a proactive approach: record incidental CVM, counsel owners about potential risks, control body weight and physical activity, and monitor at-risk dogs for early neurological signs and/or pain.

### **Limitations of this study**

The retrospective design of this study has potential limitations, including variability in neurological assessments and excessive clinical cases. The majority of the sample includes dogs with neurological symptoms, which may overestimate the true prevalence in the general population of French Bulldogs. Data collection was limited to existing clinical records, without longitudinal patient follow-up. Due to the retrospective design of the study, follow-up MRI was not available, which limits the detection of non-mineralized disc protrusions and other soft tissue lesions; therefore, CT imaging does not identify all pathological changes affecting soft tissue structures. Future combined cohort studies including both CT and MRI are needed in order to provide a more complete understanding. Angular deformities such as kyphosis and kyphoscoliosis were not quantitatively measured using standardized methods (e.g., Cobb angle). Consequently, the magnitude of spinal curvature and its potential association with neurological status or IVDD were not specifically analyzed. Despite these limitations, the CT-based findings offer strong evidence that CVM and IVDD are closely related, clinically significant spinal disorders that lead to neurological deficits in French Bulldogs. These findings contribute to the growing body of literature emphasizing the complex and multifactorial nature of spinal disease in chondrodystrophic breeds.

## **CONCLUSION**

Our study demonstrated an exceptionally high prevalence of CVM and IVDD in French bulldogs, with a significant association between these conditions and the presence of neurological deficits. This suggests that neurological symptoms have a multifactorial

origin, with CVM and IVDD often coexisting and together contributing to spinal cord compression. However, the results from this study should be interpreted with caution, as the predominance of clinically symptomatic dogs in the study population may limit their generalizability to the wider French Bulldog population.

CT has proved to be a key diagnostic method in the detection and classification of CVM, angular spinal deviations, and intervertebral disc herniations. Its superiority over conventional radiography lies in its ability to perform multiplanar reconstructions and precise evaluation of complex skeletal structures, making it an indispensable tool in the diagnosis of clinically relevant CVM. However, MRI remains essential for the detection of non-mineralized protrusions and other spinal cord pathologies, such as intramedullary tumor, syringomyelia, meningitis, edema, etc., which emphasizes the need for the combined use of both methods in a comprehensive diagnosis.

Given the clinical importance and ethical implications, early detection, increased vigilance of clinicians, and responsible breeding practices are necessary. Excluding dogs with multiple hemivertebrae or pronounced spinal deviations from breeding, together with screening using a low-dose CT protocol and genetic testing for alleles associated with the risk of IVDD, may significantly reduce the incidence of serious spinal conditions in this breed.

### **Authors' contributions**

AJ and ZV conceived and designed the study. BD, AJ, ZV, BM, PK and HC were involved in the analysis and interpretation of data. BD drafted the manuscript. MN performed the statistical analyses. BD, AJ, DM and ZV revised the manuscript critically for important intellectual content. DM and ZV supervised the manuscript. All authors gave a final approval of the version to be published and agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.


### **Declaration of conflicting interests**

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

### **Statement of Informed Consent**


The owner understood procedure and agrees that results related to investigation or treatment of their companion animals, could be published in Scientific Journal Acta Veterinaria-Beograd.


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## KONGENITALNE MALFORMACIJE PRŠLJENOVA I NJIHOVA POVEZANOST SA BOLEŠĆU INTERVERTEBRALNIH DISKOVA KOD FRANCUSKIH BULDOGA: RETROSPEKTIVNA STUDIJA KOMPJUTERIZOVANE TOMOGRAFIJE

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Kongenitalne malformacije pršljenova (CVM) česte su kod francuskih buldoga i mogu doprineti neurološkoj disfunkciji i bolesti intervertebralnih diskova (IVDD). Ova retrospektivna studija procenjivala je učestalost, tipove i raspodelu CVM pomoću kompjuterizovane tomografije (CT), kao i njihovu povezanost sa IVDD i neurološkim znacima. Analizirane su CT studije kičmenog stuba (C7–S1) kod 62 francuska buldoga pregledana u periodu od februara 2020. do februara 2025. godine. Starost pasa kretala se od 1,7 do 12 godina (srednja vrednost  $\pm$  SD,  $5,0 \pm 2,4$  godine), a 50 pasa (80,6%) ispoljavalo je neurološke znake. Kongenitalne malformacije pršljenova identifikovane su kod 57 pasa (91,9%), pri čemu su hemivertebre bile prisutne kod svih pogođenih pasa, tranzicioni pršljenovi kod 35,1%, a displazija zglobnih nastavaka kod 1,8%. Torakalne hemivertebre otkrivene su kod svih pasa sa CVM, najčešće kao višestruke lezije (94,7%), često udružene sa devijacijama kičmenog stuba, pretežno kifoskoliozom. Bolest intervertebralnih diskova dijagnostikovana je kod 58 pasa (93,5%), najčešće u lumbalnoj ili lumbosakralnoj regiji, a u 86,2% slučajeva bila je višestruka. Većina pasa sa CVM imala je i IVDD (93,0%), dok je samo pet pasa imalo IVDD bez CVM. Utvrđene su statistički značajne povezanosti između CVM i neuroloških znakova ( $\chi^2 = 66,24$ ,  $p < 0,05$ ), CVM i IVDD ( $\chi^2 = 113,85$ ,  $p < 0,05$ ), kao i između IVDD i neuroloških znakova ( $\chi^2 = 128,58$ ,  $p < 0,05$ ). Nisu uočene značajne povezanosti između pola, tipa ili broja CVM i kliničkih znakova. Ovi nalazi ukazuju na visoku učestalost CVM i IVDD kod francuskih buldoga i potvrđuju značaj CT-a u sveobuhvatnoj proceni kičmenog stuba.