**Title Page**

**Title:** Axis spinous process malformations are commonly encountered in English Bull Terriers without associated clinical signs.

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**Key Words:** cervical, vertebral malformation, congenital anomaly, spinal malformation

**Conflict of interest disclosure:** The authors declare no conflict of interest.

**Abbreviations:** CCVM, congenital cervical vertebral malformations; EBT, English Bull Terrier.

**Abstract**

Congenital cervical vertebral malformations (CCVM) have been infrequently reported in veterinary medicine, with limited examples of axis spinous process malformations. The objective of this retrospective, descriptive study was to describe the radiological characteristics, prevalence, and clinical relevance of a characteristic axis vertebral malformation in a population of English Bull Terriers (EBTs). Medical records and diagnostic imaging studies of the cervical vertebral column of EBTs presenting for any reason were reviewed and described. Based on evaluation of the images, EBTs were divided in two groups; axis spinous process malformation and normal cases. Referring veterinary surgeons were contacted for long-term follow-up information. A total of 27 cervical radiographs, 23 computed tomography and 9 magnetic resonance imaging studies from 53 EBTs were reviewed. An axis spinous process malformation, characterised by a linear defect of varying length along the base of the spinous process, was identified in 22 out of 53 EBTs (41.5%). There was no significant difference in age, body weight, or sex (P < .05) between EBTs with and without the malformation. No traumatic cause or clinical signs were identified in affected EBTs that could be directly attributed to the malformation. To the authors’ knowledge, this is the first report of a malformation of the axis spinous process in EBTs. The malformation was not associated with clinical signs and should not be misinterpreted as a traumatic vertebral fracture or other pathology.

**Introduction**

Congenital cervical vertebral malformations (CCVMs) are infrequently reported in human and veterinary medicine.1–4 Although CCVMs are considered to have a low prevalence in dogs, vertebral malformations commonly occur without associated neurological signs.2,5,6 The true prevalence of CCVMs is therefore unknown and possibly underestimated.2

In human medicine, congenital malformations affecting the axis have been classified as defects of atlantoaxial segmentation, dens dysplasia, *os odontoideum*, hypoplasia and aplasia, and segmentation failure of the axis and the C3 vertebra.2,7 Congenital malformations of the posterior elements or dorsal arch of the axis are extremely rare.7,8 A recent study describing the clinical characteristics of dogs with CCVM included two neurologically abnormal dogs with an ﻿absence of the dorsal lamina of the axis and a cleft at the level of the dorsal arch of the atlas.1 No studies have yet focused on vertebral malformations of the dorsal laminae and spinous process of the axis in dogs. At the authors’ institution, a specific malformation of the dorsal spinous process of the axis is regularly identified in English Bull Terriers (EBTs). Although this malformation has typically been seen on routine diagnostic imaging studies of EBTs without associated neurological signs, the prevalence and clinical relevance of this anomaly are currently unclear.

The primary objectives of the present study were therefore to describe the radiological characteristics, prevalence, and clinical relevance of an axis vertebral malformation in a population of EBTs.

**Material and Methods**

This retrospective study was approved by the Social Science Research Ethical Review Board of the Royal Veterinary College (RVC), University of London (URN SR2019-0428).

Electronic medical records of the RVC Small Animal Referrals hospital were searched for EBTs presenting between September 2009 and November 2019, using the following terms: “English Bull Terrier”, “Miniature Bull Terrier” and “Bull Terrier”. Dogs were eligible for inclusion if radiography, fluoroscopy, computed tomography (CT) or magnetic resonance imaging (MRI) studies including the cervical region were available for evaluation. Dogs were excluded if imaging studies did not include the axis or if medical records were not complete. Information retrieved from the medical records included signalment, weight, presenting complaint and final diagnosis.

Diagnostic imaging of the cervical vertebral column for all dogs that fulfilled the inclusion criteria were retrieved to a commercially available viewing software package for further evaluation (Horos, version 1.1.7, www.horosproject.org.). Images were reviewed by one author (J.M.F, ECVN veterinary specialist-in-training in veterinary neurology) under direct supervision of two ECVN-certified veterinary neurologists (S.D.D, J.F). Anatomical description of the axis malformation in the different imaging modalities was performed by the same authors and reviewed by an ECVDI-certified veterinary radiologist (H.D). Each dog was defined as normal or affected, according to whether the axis spinous process malformation was present or not.

In order to evaluate the presence of clinical signs associated with the axis spinous process malformation in EBT, medical records were reviewed for final diagnosis (where one was reached) and referring veterinary surgeons were contacted to complete a telephone questionnaire for follow-up information (Appendix 1). The questions evaluated the presence of cervical hyperaesthesia, gait abnormalities or external trauma to the cervical region.

Data retrieved from the medical records and imaging classification (axis spinous process malformation and unaffected cases) were recorded using a spreadsheet (Microsoft Excel for Mac, Version 16.30). Statistical analysis was performed using a commercially available statistical software package (SPSS Statistics for OSx, Version 26, IBM Corp.). Age and body weight were tested for normality using Kolmogorov-Smirnov test. As these variables were normally distributed, data was reported as mean ± standard deviation and a Student’s T-test was used to compare age and body weight between the dogs with the axis malformation and those without. The proportion of each sex was compared between the two groups using a Fisher’s exact test. Statistical significance was defined as P < .05.

**Results**

**Subjects**

Fifty-three EBTs that underwent imaging for a variety of reasons were included (Table 1). Fifteen dogs (28.3%) underwent diagnostic imaging for investigation of respiratory disease, 15 (28.3%) for a gastrointestinal condition, 8 (15.1%) for oncological disease, 6 (11.3%) for neurological disease, 2 (3.8%) for a cardiovascular condition, 2 (3.8%) for ear disease, 1 (1.9%) for renal disease, 1 (1.9%) for urogenital disease and 1 (1.9%) for wound tract exploration. Furthermore, 2 EBTs (3.8%) were referred for further investigation of a suspected axis spinous process fracture detected on radiographs with a normal physical and neurological examination and no history of trauma. EBTs with neurological disease included hydrocephalus and syringohydromyelia (n = 2), C3/C4 acute non-compressive nucleus pulposus extrusion (n = 1), cervical spondylomyelopathy (n = 1), T13/L1 intervertebral disc extrusion (n = 1), and cervical ischemic myelopathy (n = 1).

**Diagnostic investigations**

A total of 27 cervical radiographs (including 3 fluoroscopy studies), 23 CT studies and 9 MRI studies were reviewed. Four dogs had both CT and MRI studies available and 1 dog had cervical radiographs, CT and MRI. An axis spinous process malformation was identified in 22 out of 53 EBTs (41.5%), whereas 31 EBTs (58.5%) had a normal axis.

**Radiographs**

The axis spinous process malformation was observed in 16 radiographic studies. Radiographs were obtained using a Sedecal 32 kW x-ray generator and Toshiba x-ray tube and either a computed radiography (Capsula XL, Fuji) or digital radiography system (TruDR, SoundEklin). Fluoroscopy was performed using a Siemens Iconos unit (Axiom Iconos R200; Siemens Medical Solutions). All the dogs included in this group had lateral projection radiographs. In the available ventrodorsal projections (n = 4), axis spinous process malformation was not visible.

On lateral radiographs, the malformation was noted as a linear lucency extending along the base of the axis spinous process (Figure 1). In all cases the lucent line extended through the caudal, ventral margin of the spinous process. The bone margins along the level of the lucency were smooth and of increased opacity, with minimal displacement of the apposing bone fragments.

A complete defect was observed in 12 of the 16 cases (75%), as shown in Figure 1A. In these cases, the lucent line extended cranially in a mildly craniodorsal direction, before curving dorsally and extending through the dorsal margin of the spinous process at approximately the level of its cranial third. In complete defect cases, there was a variable irregularity of the bone margins at the craniodorsal extent of the defect (Figure 1A), with focal dorsal deformation of the dorsal surface of the spinous process at that level.

A partial defect was observed in 4 of the 16 cases (25%), shown in Figure 1B and 1C. In these cases, a lucent line extended from the caudal margin of the spinous process cranially in a mildly craniodorsal direction but did not extend through the dorsal margin of the spinous process. In 2 of the partial defect cases, a ‘long’ partial defect was identified whereby the lucent line extended more than 50% of the maximum spinous process length (Figure 1B). In the other 2 partial defect cases, a ‘short’ partial defect case was identified with a lucent line that extended less than 50% of the maximum spinous process length (Figure 1C).

**Computed tomography**

The axis spinous process malformation was identified in 6 CT studies. CT scans were obtained using either a 16-slice multi-detector CT (MDCT) scanner (MX 8000 IDT, Philips Medical Systems) or a 320-slice MDCT scanner (Aquilion One Genesis, Canon Medical Systems). Of the 6 dogs with axis spinous process malformation, 5 had a complete defect of the axis spinous process and 1 case was identified as a ‘long’ partial defect of the axis spinous process. On CT images, the bone margins at the level of the defect were smooth, well-defined and sclerotic, becoming more irregular at the cranial aspect of the defect when the defect was complete (Figures 2 and 3).

**Magnetic resonance imaging**

The axis spinous process malformation was observed in 2 MRI studies. MRI studies were acquired using a 1.5 Tesla Intera Pulsar System (Philips Medical Systems). Sagittal plane T2-weighted (T2-W) and short tau inversion recovery (STIR) images included the cervical region in the affected group. In both sequences, a complete defect of the axis spinous process was noted. Along the level of the defect, there was a line that was iso-to hyperintense in T2-W and hyperintense in STIR, compared to normal spinal cord parenchyma (Figure 4). There was no evidence of T2-W or STIR hyperintensity or mass effect in the surrounding bones or soft tissues.

**Clinical signs in EBTs with axis spinous process malformation**

In 19 (86.4%) of the 22 EBTs with the axis spinous process malformation, medical records revealed no clinical signs associated with the cervical region. Clinical signs associated with the cervical region were reported in the remaining 3 (13.6%) out of 22 EBTs with the malformation. One EBT was diagnosed with hydrocephalus and syringohydromyelia. Another EBT had an episode of a “stiff neck” with no pain detected on cervical palpation and no history of trauma. This dog received a short course of non-steroidal anti-inflammatory medication and the clinical signs resolved in 48 hours. The third EBT was involved in a dog fight that resulted in a small cervical bite wound. The skin laceration was superficial, and no surgical intervention was necessary.

Further follow-up information was available for 11 EBTs with the axis spinous process malformation through a telephone interview and completion of a questionnaire (Appendix 1). No cervical hyperaesthesia or any other clinical sign suggestive for a cervical problem were reported in these dogs. The median time between diagnostic investigation and the most recent history available to the referring veterinary surgeons was 24 months, ranging from 1 month to 84 months.

**Comparison between EBTs with axis spinous process malformation and normal axis.**

For EBTs affected with the axis spinous process malformation, mean age was 4.8 years (± 3.7 years, ranging from 8 months – 12 years), and for the group with a normal axis mean age was 6.3 years (± 3.9 years, ranging from 1.1 – 13.7 years). Mean body weight of the group affected with axis spinous process malformation was 23.2 kg (± 5.8 kg) and the group with a normal axis mean body weight was 24.5 kg (± 5.4 kg). In the 22 dogs with the axis spinous process malformation, there were 8 females (6 neutered), and 14 males (9 neutered). In the 31 dogs with normal axis, there were 14 females (9 neutered), and 17 males (8 neutered). There was no significant difference in age (P = 0.831), body weight (P = 0.799) or sex (P = 0.701) between EBT with and without axis spinous process malformation.

**Discussion**

In this study, we report a previously undescribed axis spinous process malformation in a population of EBT dogs. This malformation was commonly observed in EBTs without associated neurological signs and should not be misinterpreted as a traumatic vertebral fracture. The high prevalence (41.5%) in EBTs undergoing diagnostic imaging of the cervical region in this study suggests this malformation is a common incidental finding in EBTs and worthy of further investigation in other dog breeds.

The affected EBTs in this study demonstrated a characteristic defect between the lamina and dorsal spinous process of the axis (the second cervical vertebra, also known as C2), with imaging features such as smooth margins and sclerotic bone suggestive of a congenital anomaly. The axis is composed of seven bony elements in adult dogs. At birth, it consists of four bony elements: a bilateral pair of neural arch elements, a centrum 2 that forms the main part of the body of the axis and a smaller centrum 1 that is located in the base of the dens and forms the cranial aspect of the body of the axis. After birth until nearing adulthood, three more separate bone elements develop in the axis: intercentrum 2, the epiphysis, and the centrum of the proatlas.10 The dorsal arch of the axis and atlas undergo a separate embryological development. The dorsal part of the axis is derived from the caudal part of the second pair of cervical somites, while the neural arch of the atlas is derived ﻿from the caudal part of the first pair of cervical, and possibly also the last pair of occipital somites.9 As a result, this characteristic imaging finding in EBTs appears most consistent with abnormal development and ossification of the axis spinous process resulting in osseous non-union. This is supported by the presence of the malformation in EBTs as young as 8 months old in this study population. The reason why some cases had a partial defect of the axis spinous process is unknown. However, these cases more likely represent a partial failure of the ossification centres in the axis spinous process and could reflect abnormalities occurring at varying stages of abnormal development or genetic variability.

Malformations of the posterior arch in the cervical vertebral column are rarely reported in human3,7,8,10–12 and veterinary medicine.1,13,14 Axis posterior arch anomalies reported in humans include hypoplasia or aplasia of the lamina, resulting in a free-floating spinous process.7,11 Whilst anomalies of the axis posterior arch are typically incidental findings in humans,3 in rare cases they can lead to vertebral canal stenosis and neurological disfunction, requiring surgical intervention.3,7,8,10,11 Although the malformation identified in EBTs did not include hypoplasia or aplasia of the lamina or midline separation of the spinous process as reported in humans,7,10 there are similarities with affected EBTs with regards to the typically incidental nature of the finding and need to discriminate it from a traumatic fracture. A recent case series also described deficiencies of the dorsal elements of the axis in two Shih Tzu dogs, however these dogs demonstrated absence of the dorsal lamina and associated C2-C3 vertebral canal stenosis leading to neurological deficits.1

Two EBTs were referred for a suspicion of trauma based on the identification of a suspected axis spinous process fracture on cervical radiographs. These dogs did not demonstrate any neurological deficits or obvious cervical hyperesthesia. In human medicine, persistent non-union of secondary ossification centres of the vertebral spinous process have been reported to be confused with fractures.15–18 For that reason, radiographic criteria were created to help distinguish between an anomaly and an acute fracture.18 Criteria for developmental defects include smooth and sclerotic subchondral margins of both fragments, an aligned non-united spinous process, with no evidence of displacement, and, a concave margin that is continuous with the convex margin in the opposite bone.16,18,19 In contrast, acute fractures are irregular, without sclerosis, and can occur in any location. As a result, the imaging findings in the affected EBTs suggest a persistent non-union of the axis spinous process.

In 86.4% of the EBTs with the axis spinous process malformation there were no clinical signs related to the cervical region reported. Additionally, the clinical signs related to the cervical region in the remaining EBTs could not be attributed to the axis spinous process malformation. Follow up information further supported that no clinical signs suggestive of a cervical problem were reported in these dogs. One of the dogs referred for suspicion of a trauma, underwent CT and MRI with no evidence of soft tissue trauma or fractures on either imaging modality. While MRI is used as reference to assess the spinal cord and soft tissues of the vertebral column, it is not able to completely evaluate the fracture morphology.19 For that reason, CT is considered the reference standard for detection of acute vertebral bone lesions. 18,20 No evidence of an associated soft tissue trauma or bone fracture was found in the CT and MRI studies available on any of the other EBTs with the axis spinous process malformation. In combination with the lack of associated clinical signs, these findings further support the importance of recognising this malformation in EBTs to avoid unnecessary procedures or interventions.

There were no significant differences in age, body weight and sex between EBTs with and without axis spinous process malformation. In the absence of genetic information or histopathological examination, it remains currently unclear why some EBTs are affected by this malformation, while others are not. In humans, CCVM has been suggested to result from a genetic anomaly, anomalous embryonic tissue interactions and alterations in cellular migration and proliferation.7,8,21 It is possible that similar aetiologies may explain the prevalence of this malformation in EBTs and future heritance and genetic investigations could further this understanding. The prevalence of this malformation in other dog breeds is also unknown and future investigations to document this malformation in the wider dog population therefore represent an important next step.

Limitations of this study include its retrospective study design and the bias towards selection of dogs that underwent imaging in a referral hospital centre. Although no clinical signs were reported on examination or by the referring veterinary surgeons, clinical signs could have been mild or episodic. Histopathological studies of the abnormal axis spinous process would also be important to characterize this anomaly further. However, this was not possible due to the retrospective nature of the study and the lack of clinical relevance related to this anomaly.

To the authors’ knowledge, this is the first report of a characteristic malformation of the axis spinous process in a population of EBTs. The malformation was observed in EBTs without associated neurological signs and should therefore not be misinterpreted as a traumatic vertebral fracture or other pathology. Further prospective studies including histopathology and a larger and heterogenous population of dogs are necessary to clarify the aetiology and prevalence of this anomaly.

**List of Author Contributions**

Category 1

(a) Conception and Design: Fenn J, De Decker S, Frias JM

(b) Acquisition of Data: Frias JM

(c) Analysis and Interpretation of Data: Frias JM, De Decker S, Dirrig H, Fenn J

Category 2

(a) Drafting the Article: Frias JM, De Decker S, Dirrig H, Fenn J

(b) Revising Article for Intellectual Content: Frias JM, De Decker S, Dirrig H, Fenn J

Category 3

(a) Final Approval of the Completed Article: Frias JM, De Decker S, Dirrig H, Fenn J

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**Tables**

**Table 1** – Comparison of the mean age, body weight, sex and diagnostic investigations between group of dogs with axis spinous process malformation and normal axis.

|  |  |  |
| --- | --- | --- |
|  | **Normal axis (n = 31)** | **Axis spinous process malformation (n = 22)** |
| **Age** | 6.3 years (± 3.7 years) | 4.8 years (± 3.9 years) |
| **Body weight** | 23.2 kg (± 5.8 kg) | 24.5 kg (± 5.4 kg) |
| **Sex** | 14 females – 45.2%  (9 neutered)  17 males – 54.8%  (8 neutered) | 8 females – 36.4%  (6 neutered)  14 males – 63.6%  (9 neutered) |
| **Radiographs** | 11 | 16 |
| **Fluoroscopy** | 0 | 3 |
| **CT** | 17 | 6 |
| **MRI** | 7 | 2 |

**Figure Legends**

**Figure 1.** – A) Complete axis spinous process defect. Note the well-defined, smooth margins of the bone either side of the lucency running the length of the axis spinous process. The cranial aspect is slightly more irregular with some evidence of new bone formation; B) Long partial axis spinous process defect. Note the linear non-union lucency extending more than 50% the axis spinous process length; C) Short partial axis spinous process defect. Note the linear non-union lucency extending less than 50% the axis spinous process length.

**Figure 2.** – Computed tomography (CT) bone reconstruction (window width: 1500; window level: 300) of an English Bull Terrier with complete axis spinous process defect in different planes. A) Sagittal image B) Transverse image C) Dorsal image. Complete separation of the dorsal and caudal region of the spinous process is evident, with smooth, well-defined margins to the bone at this level consistent with osseous non-union. The cranial aspect (seen in A and C) is more irregular with evidence of new bone formation dorsally and laterally.

**Figure 3.** – Three-dimensional reconstructed computed tomography (CT) image of a complete axis spinous process defect in an English Bull Terrier. Note the smooth margins of the separated axis dorsal spinous process dorsally and ventrally, with a more irregular area of new bone formation at the cranial aspect.

**Figure 4.** – Magnetic resonance images (MRI) of an English Bull Terrier with a complete axis spinous process defect. A) T2-weighted (T2-W) image in sagittal plane B) Short tau inversion recovery (STIR) image in sagittal plane. In both sequences the separated axis spinous process is visible, with an iso-to-hyperintense line in the T2-W image and hyperintense line in the STIR image between the osseous portions (white arrows).