TITLE: Prevalence of thoracic vertebral malformations in french bulldogs, pugs and english bulldogs with and without associated neurological deficits

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Original Article

Prevalence of thoracic vertebral malformations in French bulldogs, Pugs and English bulldogs with and without associated neurological deficits

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Highlights

- Thoracic vertebral malformations are common in neurologically normal French bulldogs, Pugs and English bulldogs.
- There is an influence of breed on the prevalence of different types of vertebral malformations.
- Hemivertebrae occur more often in neurologically normal French bulldogs and less often in Pugs.
- Transitional vertebrae and spina bifida occur more often in neurologically normal Pugs.
- Hemivertebrae are more likely to be associated with neurological deficits in Pugs than the other breeds.

Abstract

Congenital vertebral malformations are common incidental findings in small breed dogs. This retrospective observational study evaluated the type and prevalence of thoracic vertebral malformations in 171 neurologically normal and 10 neurologically abnormal screw-tailed brachycephalic dogs. Neurologically normal dogs underwent CT for reasons unrelated to spinal disease, while affected dogs underwent MRI. Imaging studies were reviewed and vertebral malformations including hemivertebrae, block vertebrae, transitional vertebrae, and spina bifida were documented.

The group of clinically normal dogs consisted of 62 French bulldogs, 68 Pugs and 41 English bulldogs. The group of affected dogs consisted of one French bulldog and nine Pugs. Overall, 80.7% of neurologically normal animals were affected by at least one vertebral malformation. There was a significant influence of breed, with thoracic vertebral malformations occurring more often in neurologically normal French bulldogs (P<0.0001) and English bulldogs (P=0.002). Compared to other breeds, hemivertebrae occurred more often in neurologically normal French bulldogs (93.5%; P< 0.0001 vs. Pugs; P=0.004 vs. English bulldogs) and less often in neurologically normal Pugs (17.6%; P=0.004 vs. English bulldogs). Neurologically normal Pugs were more often diagnosed with transitional vertebrae

and spina bifida compared to other breeds (P<0.0001 for both malformations). Of Pugs included in the study, 4.7% were diagnosed with clinically relevant thoracic vertebral malformations. When compared to the general veterinary hospital population, this was significantly more than the other two breeds (P= 0.006). This study indicates that thoracic vertebral malformations occur commonly in neurologically normal screw-tailed brachycephalic dogs. While hemivertebrae are often interpreted as incidental diagnostic findings, they appear to be of greater clinical importance in Pugs compared to other screw-tailed brachycephalic breeds.

Keywords: Brachycephalic; Hemivertebra; Kyphosis; Spina bifida; Transitional vertebra

Introduction

Congenital vertebral malformations are common incidental findings in small brachycephalic dogs. Although the terminology used for these malformations is controversial, they have been classified as defects in segmentation (block vertebrae), defects in formation (wedge or hemivertebrae) and other defects, including transitional vertebrae and spina bifida (Westworth and Sturges, 2010). Hemivertebrae are frequently reported in screw-tailed brachycephalic breeds such as the French bulldog (Moissonnier et al., 2011; Aikawa et al., 2014; Gutierrez-Quintana et al., 2014). Although the exact aetiology is unclear, they are assumed to be hereditary (Schlensker and Distl, 2016). These vertebral malformations are most frequently found in the thoracic vertebral column and can affect single or multiple vertebrae (Faller et al., 2014; Guevar et al., 2014).

Despite the potential to cause clinical signs of spinal cord dysfunction, vertebral malformations are frequently not associated with disease. Approximately 78% of neurologically normal French bulldogs had radiographic evidence of hemivertebrae, with or without spinal kyphosis (Moissonnier et al., 2011). This indicates that caution should be used when evaluating imaging studies of French bulldogs with suspected spinal disease (Dewey et al, 2016). More specifically, other spinal conditions, including intervertebral disc disease (Aikawa et al., 2014) and spinal arachnoid diverticula (Mauler et al., 2014), should be considered more likely causes of clinical signs in French bulldogs with thoracic vertebral body malformations. Vertebral body malformations can result in alterations of vertebral angulation, such as spinal kyphosis and scoliosis. Although the development of clinical signs in dogs with congenital vertebral body malformations is thought to be multifactorial in aetiology, it has been suggested that spinal kyphosis is a key factor in the development of clinical signs and that kyphosis needs to reach a threshold point before clinical signs are

likely to occur (Moissonnier et al., 2014; Guevar et al., 2014). Although this situation is well recognised for French bulldogs (Moissonnier et al., 2011), it is currently unknown if other screw-tailed brachycephalic dogs demonstrate a similar prevalence of clinically irrelevant thoracic vertebral malformations.

The primary aims of this study were to describe and compare the type and prevalence of thoracic vertebral malformations in French bulldogs, Pugs and English bulldogs with and without associated neurological deficits. It was hypothesised that although thoracic vertebral malformations would occur commonly in each of the three evaluated breeds, they would only rarely result in spinal cord dysfunction. Our secondary hypothesis was that the prevalence of thoracic vertebral malformations would be breed-associated.

Materials and methods

The digital medical database of the Small Animal Referral Hospital, Royal Veterinary College, was reviewed between October 2010 and February 2016 to identify two groups of dogs. Group 1 included French bulldogs, Pugs and English bulldogs which underwent thoracic CT under sedation or general anaesthesia for reasons unrelated to spinal disease. Dogs were excluded if medical records or imaging studies were incomplete or unavailable for review, or if the dog demonstrated a gait abnormality. A study was considered incomplete if the complete thoracic vertebral column was not included. Group 2 included French bulldogs, Pugs and English bulldogs with clinically relevant vertebral malformations diagnosed by MRI under general anaesthesia. A vertebral malformation had to be the only identified cause of spinal dysfunction in these dogs.

Information retrieved from the medical records included signalment, reason for presentation, results of general physical examinations and, if available, neurological examinations. CT was performed with a 16-slice helical CT scanner (PQ 500, GE Healthcare), 2 mm slice thickness and -1 interval between slices After completion of the axial CT study, sagittal, dorsal and 3D reconstructions were made. MRI was performed with a 1.5 Tesla magnet and included a minimum of T2 –and T1 – weighted sagittal and transverse images. Slice thickness was 3.5 mm in all planes with an interslice gap of 0.9 mm in the sagittal planes and 1 mm in the transverse planes. Imaging studies were independently evaluated by two observers (RR and RGQ for CT studies; RR and SDD for MRI studies), after which a consensus opinion was reached. The observers were not masked to the breed of dog. For each imaging study, the number of thoracic vertebrae were recorded and each thoracic vertebra was subsequently assessed for the presence of hemivertebra, block vertebra, spina bifida and transitional vertebra (Fig. 1). Hemivertebrae were defined as any defect in vertebral body formation as outlined by Gutierrez-Quintana et al (2014). Block vertebrae were defined as failure of vertebral segmentation with absence of the intervertebral disc space between two adjacent vertebral bodies (Westworth and Sturges, 2010). Spina bifida was defined as incomplete closure of the vertebral arches resulting in a cleft through the dorsal spinous process (Westworth and Sturges, 2010). Transitional vertebrae were defined as thoracic vertebrae at the cervicothoracic or thoracolumbar junctions displaying characteristics of cervical or lumbar vertebrae, respectively, including the absence or hypoplasia of a rib or an abnormal transverse process (Westworth and Sturges, 2010). Standard image archiving and communication system software (Osirix Foundation, V.5.5.2) was used to evaluate all imaging studies.

Statistical methods

Data was analysed using commercial software (IBM SPSS Statistics version 22). Association between breed and total number of malformations, and the total number of hemivertebrae and block vertebrae, was evaluated with Kruskal-Wallis tests. Post-hoc analysis with Mann-Whitney tests was used to determine the relative prevalence in each breed. The presence of spina bifida and transitional vertebra and the prevalence of clinically relevant vertebral malformations were determined using Fisher's exact tests; Pugs were compared to the other breeds as a collective. Values of $P < 0.05$ were considered statistically significant for all analyses; the significance level for multiple comparisons was adjusted for using the Bonferroni method.

Results

Dogs without neurological signs

A total of 171 dogs, comprising 62 French bulldogs, 68 Pugs and 41 English bulldogs were included in this group. All underwent CT for a variety of clinical indications, including brachycephalic obstructive airway syndrome (*n*=124), other respiratory disease, neoplastic disease (*n*=17 for both), cardiac disease (*n*=5), gastrointestinal disease, and trauma (*n*=4 for both). CT imaging did not reveal any malformations in 33 dogs (19.3%), while single (*n*= 36) or multiple (*n*=102) malformations were observed in 138 dogs (80.7%).

The group of French bulldogs consisted of 52 males and 10 females between 2 and 135 months old (median, 19.5; mean, 29.9 months) and weighing between 6.7 and 16 kg (median, 11.45; mean, 11.4kg). All French bulldogs had 13 thoracic vertebrae. Four (6.5%) French bulldogs had no thoracic vertebral malformations, while 58 (93.5%) had one or more hemivertebrae. A total of 243 hemivertebrae were present; nine (14.5%) dogs had single hemivertebrae and 49 (79.0%) had multiple hemivertebrae. T9 was most often affected (*n*=31

dogs), followed by T10 (*n*=30), T5 and T6 (*n*=29 for both). Block vertebrae were diagnosed in four (6.5%) French bulldogs; T11-T12 (*n*=4) were most often affected, followed by T12-T13 (*n*=2). Fourteen (22.6%) dogs had fused dorsal spinous processes. Transitional vertebrae were present in three French bulldogs (4.8%). In these dogs, T13 had characteristics of a lumbar vertebra. Four (6.5%) dogs had vertebrae with evidence of more than one type of malformation. These consisted of block and hemivertebrae (*n*=3) and spina bifida and hemivertebrae (*n*=1) combinations. No French bulldogs in this population had evidence of spinal bifida alone.

The group of Pugs consisted of 31 males and 37 females between 4 and 151 months old (median, 31.5; mean, 42.7 months) and weighing between 4 and 14kg (median, 8.15; mean, 8.3kg). Seventeen (25.0%) Pugs had only 12 thoracic vertebrae. Eighteen (26.5%) Pugs had no thoracic vertebral malformations. Twelve (17.6%) Pugs had hemivertebrae. A total of 19 hemivertebrae were present; six (8.8%) Pugs had single hemivertebrae and six had multiple hemivertebrae. The most commonly affected vertebra was T8 (*n*=8), followed by T7 (*n*=5) and T9 (*n*=3). No Pugs had block vertebrae or fused spinous processes. Transitional vertebrae were present in 21 Pugs (30.9%). T13 in these dogs had characteristics of a lumbar vertebra. Twenty-six (38.2%) Pugs had spina bifida. This anomaly was exclusively observed at T1.

The group of English bulldogs consisted of 29 males and 12 females between 10 and 132 months old (median, 21.0; mean, 40.9 months) and weighing between 10.3 and 37.1kg (median, 23.25; mean, 23.9kg). All dogs had 13 thoracic vertebrae. Ten (24.4%) English bulldogs had no thoracic vertebral malformations. Thirty (73.2%) dogs had hemivertebrae. A total of 100 hemivertebrae were present; three (7.3%) dogs had single hemivertebrae and 27

(65.9%) had multiple hemivertebrae. The most commonly affected vertebra was T9 (*n*=18), followed by T7 (*n*=14) and T8 (*n*=13). Block vertebrae were diagnosed in four (9.8%) dogs, with T11-T12 (*n*=3) being most frequently affected, followed by T12-T13 (*n*=1). Eight (19.5%) English bulldogs had fused dorsal spinous processes. Transitional vertebrae were present in four (9.8%) English bulldogs. In three of these dogs, T13 had characteristics of a lumbar vertebra and in one dog, T1 had characteristics of a cervical vertebra. One (2.4%) English bulldog had evidence of spina bifida at T10. Two English bulldogs had vertebrae with characteristics of more than one type of malformation, which consisted of transitional vertebra and hemivertebra (*n*=1) and a transitional and block vertebra (*n*=1).

Dogs with clinically relevant vertebral malformations

During the study period, a total of 105 French bulldogs, 192 Pugs and 120 English bulldogs were presented for a wide variety of clinical indications (neurological and non-neurological) at the Small Animal Referral Hospital, Royal Veterinary College. Of these dogs, one French bulldog (0.95% of all French bulldogs presented) and nine Pugs (4.7% of all pugs presented) were diagnosed with a thoracic vertebral malformation as the cause of their clinical signs. These 10 affected dogs included eight males and two females, aged between 4 and 57 months (median, 8.0 months; mean, 20.0). Duration of clinical signs at presentation varied from 7 days to 2 years (median, 61 days; mean, 173 days) and consisted of ambulatory paraparesis and ataxia of the pelvic limbs in all dogs. Spinal hyperaesthesia could be elicited in two dogs. In each of these dogs, thoracic hemivertebrae were the cause of their clinical signs (Fig. 2). Other abnormalities, not considered to be associated with clinical signs, included spina bifida at the level of T1 in three Pugs and a transitional T13 vertebra in two Pugs.

Comparison between breeds

There was a significant influence of breed on the overall prevalence of thoracic vertebral malformations in neurologically normal dogs ($P< 0.0001$). More specifically, neurologically normal French bulldogs had significantly more thoracic vertebral malformations than neurologically normal Pugs ($P< 0.0001$). Neurologically normal English bulldogs had significantly more thoracic vertebral malformations than neurologically normal Pugs ($P= 0.002$). There were no significant differences between the other individual breeds ($P >0.01$). There was a significant influence of breed on the prevalence of hemivertebrae in neurologically normal dogs ($P< 0.0001$). Hemivertebrae were diagnosed more often in neurologically normal French bulldogs than in neurologically normal Pugs ($P< 0.0001$) and English bulldogs ($P= 0.004$). Hemivertebrae were diagnosed less often in neurologically normal Pugs than in neurologically normal English bulldogs ($P= 0.004$). There was a significant influence of breed on the prevalence of spina bifida and transitional vertebrae in neurologically normal dogs, with Pugs significantly more often affected compared to the other two breeds ($P< 0.0001$ for both malformations). There was no significant influence of breed on the prevalence of block vertebrae in neurologically normal dogs ($P= 0.086$).

Finally, there was a significant influence of breed on the prevalence of clinically relevant thoracic vertebral malformations, with Pugs being overrepresented compared to the other two breeds ($P= 0.006$).

Discussion

This study described and compared thoracic vertebral malformations in French bulldogs, Pugs and English bulldogs with and without associated neurological deficits. The results of this study support previous reports indicating a high prevalence of vertebral

239 malformations in neurologically normal screw-tailed brachycephalic breeds (Moissonnier et
240 al., 2011; Guevar et al., 2014; Gutierrez-Quintana et al., 2014). Overall, 80.7% of
241 neurologically normal animals were affected by at least a single malformation and 59.6% had
242 multiple malformations. This is comparable to previous work reporting a 64.2% prevalence
243 of multiple thoracic malformations in a population of neurologically normal and abnormal
244 brachycephalic screw-tailed dogs (Gutierrez-Quintana et al., 2014). This information has
245 clinical importance for the interpretation of imaging studies in animals with suspected spinal
246 disease and underlines the importance of questioning the clinical relevance of vertebral
247 malformations observed on radiological studies. This is highlighted by the fact that, although
248 thoracic vertebral malformations were commonly encountered on imaging studies, they were
249 only rarely considered the direct cause of clinical signs in the studied breeds. While the
250 prevalence of clinically relevant thoracic vertebral malformations was 4.7% in our hospital
251 population of Pugs overall, the clinical importance of this diagnosis was negligible in the
252 other two breeds.
253
254 Hemivertebrae were the most frequently diagnosed vertebral malformation in French
255 bulldogs and English bulldogs, which is consistent with previous publications (Westworth
256 and Sturges 2010; Moissonnier et al., 2011; Faller et al., 2014; Gutierrez-Quintana et al.,
257 2014). Additionally, the most frequent location for hemivertebrae was in the mid thoracic
258 region (T7-T9; Moissonnier et al., 2011; Faller et al., 2014; Guevar et al., 2014; Gutierrez-
259 Quintana et al., 2014). In our study, French bulldogs were significantly overrepresented for
260 hemivertebrae compared to the other breeds, with over 90% of neurologically normal animals
261 affected and the majority of cases showing multiple hemivertebrae. Interestingly, while
262 hemivertebrae occurred significantly less common in neurologically normal Pugs,
263 hemivertebrae accompanied by neurological deficits was diagnosed significantly more often

in this breed compared to the two other breeds. This finding suggests that although hemivertebrae are less common in Pugs, this type of vertebral malformation is more likely to be associated with the development of clinical signs in this breed. It is currently unclear why hemivertebrae are more often associated with clinical signs in Pugs compared to French and English bulldogs. A recent study proposed a classification system of canine hemivertebrae into seven different subtypes (Gutierrez-Quintana et al., 2014). Development of clinical signs in animals with hemivertebrae is thought to have a multifactorial aetiology, with vertebral instability and vertebral canal stenosis considered to be contributing factors (Westworth and Sturges, 2010; Moissonier et al., 2011; Dewey et al., 2016). Hemivertebrae can result in an abnormal angulation of the vertebral column, referred to as kyphosis or scoliosis (Moissonnier et al., 2011; Aikawa et al., 2014; Faller et al., 2014; Guevar et al., 2014). Recent studies have suggested that severity of kyphosis is a key factor in the development of clinical signs in dogs with hemivertebrae and that a certain degree of vertebral kyphosis must be exceeded before clinical signs are likely to occur (Moissonnier et al., 2011; Guevar et al., 2014). Although beyond the scope of this study, it is possible that Pugs are affected by a different subtype of hemivertebrae which results in more severe kyphosis. Further studies are therefore needed to evaluate the influence of breed on hemivertebra subtype and the influence of hemivertebra subtype on the degree of vertebral kyphosis.

Pugs were significantly more often diagnosed with thoracolumbar transitional vertebrae compared to French bulldogs and English bulldogs. In almost one third of neurologically normal Pugs, T13 demonstrated characteristics of both thoracic and lumbar vertebrae, including unilateral or bilateral absence of ribs and the presence of rudimentary transverse processes. Although transitional vertebrae are not considered a direct cause of spinal cord dysfunction, these anomalies have been associated with alterations in vertebral

biomechanics and can complicate the approach of routine spinal surgeries (Morgan et al., 1968; Flückiger et al., 2006; Westworth and Sturges, 2010).

Spina bifida refers to failure of closure of one or more vertebral arches over the spinal cord. It is categorised based on the level of neuroectoderm involved, and subtypes include aperta (open), cystica (closed) and occulta (hidden; Song et al., 2016). It has been reported in a variety of breeds and is probably related to genetic and environmental causes (Wilson et al., 1979; Song et al., 2016). Less severe malformations are commonly encountered without clinical signs, with malformations typically found incidentally on diagnostic studies (Song et al., 2016). Our study reported that spina bifida occulta was an infrequent finding in English and French bulldogs as only one case identified among these dogs, which is similar to the findings of previous studies of comparable populations (Gutierrez-Quintana et al., 2014). In contrast, in our study, Pugs were affected by thoracic spina bifida occulta significantly more often than other breeds and this abnormality was found exclusively at T1. It is currently unclear why spina bifida occulta was only present at T1 and what the clinical relevance of this finding may be. This information should however be taken into account when evaluating imaging studies of Pugs with suspected spinal disease.

Our study was limited by its retrospective design which meant the majority of this population of dogs did not receive a neurological examination. Therefore, we cannot exclude the possibility that a number of animals developed clinical signs relating to vertebral malformations later in life. However, the retrospective study design enabled the inclusion of a large population of dogs. Furthermore, neurologically normal animals underwent CT imaging, while clinically affected dogs underwent MR imaging. Both advanced imaging techniques are associated with specific advantages and disadvantages and differ clearly in

their diagnostic potential for imaging the bony vertebral column and the parenchymal spinal cord. Therefore, we decided not to compare imaging findings of affected and unaffected dogs directly. Although not evaluated in this study, further classification of hemivertebra subtype might have determined whether a specific hemivertebra subtype was more prevalent in one of the studied breeds and if there was an association with different degrees in spinal kyphosis. A previous study has demonstrated differences in hemivertebra subtyping when survey radiographs and CT were compared (Brocal et al., 2016). It is possible that differences would also exist when comparing MRI and CT. For this reason, a comparison of hemivertebra subtypes in affected and unaffected dogs was not attempted in our study. It is unclear whether a classification system designed to evaluate specific bony vertebral body abnormalities could be used reliably for MRI.

Conclusions

There is a high prevalence of vertebral malformations in neurologically normal 'screw-tailed' brachycephalic breeds and there is a significant influence of breed on the prevalence of each type of malformation. Neurologically normal French bulldogs are significantly more often diagnosed with hemivertebrae than neurologically normal Pugs and English bulldogs, while neurologically normal Pugs are diagnosed with hemivertebra significantly less frequently than neurologically normal French and English bulldogs. However, Pugs are diagnosed with hemivertebra as the cause of neurological deficits more often than the other breeds evaluated. Further studies are needed to evaluate the influence of breed on hemivertebra subtype and the influence of hemivertebra subtype on the degree of vertebral kyphosis.

Conflict of interest statement

None of the authors has a financial or personal relationship with people or organisations that could inappropriately influence or bias the content of this paper.

References

Aikawa, T., Shibata, M., Asano, M., Hara, Y., Tagawa, M., Orima, H., 2014. A comparison of thoracolumbar intervertebral disk extrusion in French bulldogs and Dachshunds and association with vertebral anomalies. Veterinary Surgery 202, 267– 273.

Brocal, J., De Decker, S., Jose-Lopez, R., Guevar, J., Ortega, M., Ter Haar, G., Gutierrez-Quintana, R., 2016. Comparison of the accuracy of radiography and conventional computed tomography for detection of congenital thoracic vertebral malformations in brachycephalic 'screw-tailed' dog breeds. Journal of Veterinary Internal Medicine 30,1950.

Dewey, C.W., Davies, E., Bouma, J.L., 2016. Kyphosis and kyphoscoliosis associated with congenital malformations of the thoracic vertebral bodies in dogs. Veterinary Clinics of North America: Small Animal Practice 46, 295– 306.

Faller, K., Penderis, J., Stalin, C., Guevar, J., Yeamans, C., Gutierrez-Quintana, R., 2014. The effect of kyphoscoliosis on intervertebral disc degeneration in dogs. The Veterinary Journal 200, 449– 451.

Flückiger, M.A., Damur-Djuric, N., Hässig, M., Morgan, J.P., Steffen, F., 2006. A lumbosacral transitional vertebra in the dog predisposes to cauda equina syndrome. Veterinary Radiology and Ultrasound 47, 39– 44.

Guevar, J., Penderis, J., Faller, K., Yeamans, C., Stalin, C., Gutierrez-Quintana, R., 2014. Computer-assisted radiographic calculation of spinal curvature in brachycephalic 'screw-tailed' dog breeds with congenital thoracic vertebral malformations: reliability and clinical evaluation. PloS One 9, e106957.

Gutierrez-Quintana, R., Guevar, J., Stalin, C., Faller, K., Yeamans, C., Penderis, J., 2014. A proposed radiographic classification scheme for congenital thoracic vertebral malformations in brachycephalic 'screw-tailed' dog breeds. Veterinary Radiology and Ultrasound 55, 585– 591.

Mauler, D.A., De Decker, S., De Risio, L., Volk, H.A., Dennis, R., Gielen, I., Van der Vekens, E., Goethals, K., Van Ham, L., 2014. Signalment, clinical presentation, and diagnostic findings in 122 dogs with spinal arachnoid diverticula. Journal of Veterinary Internal Medicine 28, 175– 181.

Morgan, J.P., 1968. Congenital anomalies of the vertebral column of the dog: a study of the incidence and significance based on a radiographic and morphologic study. Journal of the American Veterinary Radiology Society 9, 21– 29.

Moissonnier, P., Gossot, P., Scotti, S., 2011. Thoracic kyphosis associated with hemivertebra. Veterinary Surgery 40, 1029– 1032.

Schlensker, E., Distl, O., 2016. Heritability of hemivertebrae in the French bulldog using an animal threshold model. The Veterinary Journal 207, 188– 189.

Song, R.B., Glass, E.N., Kent, M., 2016. Spina bifida, meningomyelocele, and meningocele. Veterinary Clinics of North America: Small Animal Practice 46, 327– 345.

Westworth, D.R., Sturges, B.K., 2010. Congenital spinal malformations in small animals. Veterinary Clinics of North America: Small Animal Practice 40, 951– 981.

Wilson, J.W., Kurtz, H.J., Leipold, H.W., Lees, G.E., 1979. Spina bifida in the dog. Veterinary Pathology 16, 165– 179.

Fig. 1. Sagittal reconstructed (A and B), transverse and three-dimensional reconstructed CT images illustrating the evaluated thoracic vertebral malformations; hemivertebra (A), block vertebra (B), spina bifida (C) and a thoracolumbar transitional vertebra (D). Vertebral malformations indicated by white arrow.

Fig. 2. (A) T2-weighted sagittal and (B) T1-weighted sagittal magnetic resonance images of a 9-month old Pug with a clinically relevant thoracic vertebral body malformation. Hemivertebra indicated by white arrow.