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Surgical treatment of dorsal hemivertebrae associated with kyphosis by spinal segmental stabilisation, with or without decompression

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Highlights

- We recruited surgically treated dogs with symptomatic dorsal hemivertebrae and kyphosis.
- We assessed the spinal segmental stabilisation technique, with or without decompression.
- A good to excellent long-term outcome was demonstrated in most cases.
- Immediate or delayed post-operative complications occurred in some cases.
- Further adaptions of the technique to prevent implant loosening are needed.

Abstract

This retrospective case series examined the effectiveness of spinal segmental stabilisation, with or without decompression, in nine dogs with neurological deficits associated with dorsal hemivertebrae. Data on signalment, preoperative neurological status, imaging findings, surgical techniques and outcome were evaluated.

All cases occurred in young or adult, small-breed dogs with neurological signs ranging from progressive moderate pelvic limb ataxia to non-ambulatory paraparesis. Six dogs also showed urinary and faecal incontinence. In each dog, one or more dorsal thoracic hemivertebra(e) were detected by radiography and MRI. In all dogs, hemivertebra(e) were associated with kyphosis and reduced vertebral canal diameter. All dogs were surgically managed with spinal segmental stabilisation, using Steinmann pins and orthopaedic wires and/or sutures attached to the spinous processes. Three dogs also underwent additional decompressive surgery. Post-operative follow-up ranged from 1.5 to 5.5 years.

Immediate or delayed post-operative complications occurred in three dogs, including implant migration or loosening. Eight dogs showed long-term gait improvement, with resolution of incontinence if previously present. At 2 to 6 years post-surgery, four dogs were neurologically normal, three had mild residual ataxia, one had moderate ambulatory paraparesis, and one dog relapsed 3.5 years after surgery, resulting in severe paraparesis. Spinal segmental stabilisation techniques, with or without decompression, can result in a satisfactory outcome in small dogs with hemivertebrae and mild to moderate neurological signs. Further adaptations might be required to avoid implant loosening and allow continued growth in immature dogs.

Keywords: Kyphosis; Vertebral malformation; Dog; Spinal stabilisation; Neurological deficits

Introduction

Congenital vertebral malformations are commonly observed in the thoracic spine of small, screw-tailed dog breeds (Bailey and Morgan, 1992). In most cases they are incidental imaging findings (Done et al., 1975; Bailey and Morgan, 1992; Jeffery et al., 2007; Meheust and Robert, 2010; Moissonnier et al., 2011) but vertebral malformations can result in vertebral column malangulation that can lead to vertebral canal stenosis and static spinal cord compression (Philips et al., 1997). In addition, they can create vertebral instability, causing acute or repetitive spinal cord injury due to dynamic compression (Shapiro and Herring, 1993; Philips et al., 1997; Hughes et al., 1998).

Failure of formation of the vertebral body during the developmental phases of chondrification and resegmentation, also called type I congenital vertebral malformation, typically leads to abnormal vertebral body shapes, i.e. wedge shaped vertebrae, vertebral body shortening, or other shape alterations, such as butterfly vertebra. The general term ‘hemivertebra(e)’ has been used for all these abnormalities (Tanaka and Uhthoff, 1981; Kirberger, 1989; Bailey and Morgan, 1992). Dorsal, ventral and lateral wedging of the vertebral body, might result in pressure-induced malformation of adjacent vertebral bodies and/or abnormal spinal curvature (kyphosis, lordosis or scoliosis, respectively; Bailey and Morgan, 1992). The terms dorsal, ventral and lateral (wedge-shaped) hemivertebrae, respectively, will be used here.

Surgical management of cases with clinical signs associated with hemivertebra with vertebral column malangulation can be challenging, and there are only a few reports of such cases in the veterinary literature. A single case report describes a successful outcome in a young Labrador retriever following partial ventral corpectomy and fixation with pins and polymethylmethacrylate (PMMA; Meheust and Robert, 2010). Two case series describe a total of 12 small breed dogs treated with fixation using pins and PMMA, with or without hemilaminectomy, with good outcomes reported in 11/12 dogs (Aikawa et al., 2007; Jeffery et al., 2007). In one of those dogs, segmental stabilisation with two Steinman pins and polypropylene sutures combined with PMMA was used (Jeffery et al., 2007).

Our study is the first case series to describe and assess the outcome of spinal segmental stabilisation either as a sole therapy, or combined with decompression, for the management of clinically significant dorsal hemivertebrae. The surgical technique, with pins and wires and/or sutures, was based on the previously reported 'spinal stapling' technique used primarily for the management of fractures in small-breed dogs (Cage, 1973; Matthiesen, 1983; Mcanulty et al., 1986), and subsequently modified (Mcanulty et al., 1986). Clinical data were reviewed for all cases treated by spinal segmental stabilisation at three institutions with post-operative follow-up ranging from 1.5 – 5.5 years.

Materials and methods

Inclusion criteria

Medical records (2008-2013) for dogs with clinical hemivertebrae that were surgically managed by spinal segmental stabilisation, with or without concomitant decompressive procedures, were retrieved from the clinical databases of the Queen's Veterinary School Hospital, University of Cambridge, the Hixson-Lied Small Animal Hospital, Iowa State

University and the Small Animal Teaching Hospital, University of Liverpool. Only cases with complete medical records and radiographic and magnetic resonance imaging (MRI) records were included.

Data retrieved

Information extracted from the medical records for each case included signalment, duration of clinical signs prior to presentation, neurological findings at first consultation, survey radiographic and MRI findings, results following conservative management, surgical procedures performed, neurological findings immediately following surgery, at discharge, and at first revisit (1-6 months post-operatively). Long-term outcome was assessed by serial re-examination of each dog at the participating hospital (except for dog 4) and/or telephone interviews with the owner (all dogs). Post-operative follow-up time varied between 1.5 and 5.5 years.

Neurological status

A full neurological examination was performed in each dog pre-operatively and at variable time points post-operatively. A grading scale was created to define the gait abnormalities and neurological deficits in each dog, allowing comparisons between the different assessment times (Table 1). The score for each dog was derived retrospectively, i.e. based on clinical notes, for the first presentation and rechecks, except for the last recheck, for which the score was derived prospectively. Usually, the same clinician at each centre evaluated the neurological status of each case from the initial presentation to the final recheck.

Neuroimaging

Lateral and ventrodorsal radiographic projections of the spine were evaluated. The modified Cobb method was used to measure the vertebral column malangulation (McMaster and Singh, 2001; Moissonnier et al., 2011). In this method, the angle formed between two lines drawn parallel to the cranial extremity of the most cranial vertebra and the caudal extremity of the most caudal vertebra of the vertebral column malangulation was measured on lateral radiographs, at initial presentation (Fig. 1). Sagittal and transverse T1-weighted and T2-weighted MR images of the thoracic vertebral column were obtained using a 0.25 T (MR GRANDE S.P.A., Esaote; dogs 1-3), 1.5 T (Signa Excite, GE Healthcare; dogs 4-6) or 1 T (Magnetom, Siemens; dogs 7-9) magnet. The MR images were examined for possible associated spinal cord lesions. Vertebral canal stenosis was quantified on T2-weighted MR images by the division of the vertebral canal height (distance between the ventral and the dorsal surface of the vertebral canal) at the site of the most severe compression, relative to the canal height at T2 vertebral level. The result was expressed as a percentage reduction in vertebral canal height. One person (MC) measured the modified Cobb angle and the vertebral canal height reduction of all the cases.

Surgical procedure

Spinal segmental stabilisation with Steinmann pins and orthopaedic wires (or polypropylene sutures) was performed to stabilise the spine at the level of the hemivertebra and its adjacent vertebrae, as previously described (McAnulty et al., 1986; Jeffery et al., 2007). A bilateral dorsal approach was made to the thoracic vertebral column with preservation of the supraspinous ligament, interspinous ligaments and caudal articular processes. The size, length and number of the Steinmann pin(s) were based on dog size, age and imaging findings.

Orthopaedic wires were attached to the spinous processes. In two cases, polypropylene sutures (Prolene, Ethicon) were used in combination with orthopaedic wires.

In three cases, partial lateral corpectomy (Moissonnier et al., 2004; Flegel et al., 2011) or dorsal laminectomy was additionally performed at the level of vertebral canal stenosis. As part of the corpectomy, pediculectomy, also referred to as mini-hemilaminectomy (Jeffery, 1988), was performed at the initial stages of the procedure on the same side as the corpectomy. The decision as to whether or not decompression was performed was mainly dependent on the surgeon's preference, rather than the degree of spinal cord compression.

Radiographs were taken immediately after surgery in all dogs to ensure the correct placement of the implants. Post-operative analgesia was dependent on the requirements of each dog, and consisted of a combination of non-steroidal anti-inflammatory drugs, opioids and/or ketamine/lidocaine continuous infusions.

Results

Signalment

Nine dogs met the criteria for inclusion (Table 2). All were small and screw-tail breeds, including six Pugs, two English bulldogs and one Pomeranian. There were four males and five females and median age at presentation was 9 months (mean, 27 months; range, 2 - 82 months). Median weight was 7 kg (mean, 10 kg; range, 4.8 to 20.6 kg), and two dogs (dogs 4 and 6) were considered obese (based on the standard body condition scoring).

Clinical signs

Median age of onset was 7 months (mean, 26 months; range, 2 - 79 months); there was early onset of clinical signs (< 9 months) in six dogs and an adult-onset (> 1 year) in the remaining three (Table 2). The mean duration of neurological signs before the initial presentation was 1 month (range, 1 day - 3 months). In dog 3, mild trauma was associated with the onset of clinical signs; no known triggers were found in the other dogs. All dogs, apart from two for which clinical signs had an acute (dog 6) or sub-acute (dog 3) onset, showed a chronic progressive course. Urinary and faecal incontinence were reported in five dogs at initial presentation.

Seven dogs showed moderate to severe ambulatory paraparesis at initial presentation and two dogs were non-ambulatory paraparetic (Table 3). The clinical signs were asymmetrical in six dogs (1, 2, 3, 6, 8 and 9) and symmetrical in the other three dogs (4, 5 and 7). Discomfort was noted on palpation of the thoracic spine in three dogs (2, 3 and 6). The cutaneous trunci reflex was interrupted at the mid-thoracic spine in four dogs (1, 2, 3 and 6). Cage rest was initially attempted in three dogs (2, 3 and 7). In dogs 2 and 7, no change in the neurological status was observed after 1 month. Dog 3 became non-ambulatory paraparetic and also developed urinary and faecal incontinence after 2 months of conservative management.

Radiography and CT findings

All dogs had abnormalities (Table 2) of the thoracic vertebral column with single or multiple dorsal wedge shaped hemivertebra(e) between T4 and T9 (Fig. 1). A butterfly vertebra was also present at T11 in dog 6. Two dogs (2 and 3) had 12 thoracic vertebrae and one of these dogs (3) had a lumbosacral transitional vertebra. All dogs had kyphosis; this was centred at T4-T7 (7), T5-6 (1), T5-8 (8 and 9), T7 (2), T7-8 (5), T7-9 (3) and T8-9 (4 and 6). The median degree of vertebral column malangulation was 30.5 ° (mean, 35 °; range, 10-68 °; Table 2). In addition, dog 3 had mild scoliosis at T3-9.

MRI findings

Vertebral canal stenosis (Fig. 2) was observed in all dogs. The reduction of the vertebral canal height at the area of the highest degree of stenosis varied between 27% and 88% (mean, 64%; Table 2). Mild intervertebral disk protrusions were observed at T6-T7 in dog 1, and at T6-T7 and T7-T8 in dog 5. The central canal was mildly dilated (10 mm in length and 4 mm in diameter) in one dog (5) at T7-8 just caudal to the vertebral malformation. This finding was hyperintense on T2-weighted and hypointense on T1-weighted images, compatible with syringomyelia.

Surgical procedure

In all cases, the site of spinal cord compression was approached via a midline dorsal skin incision. While preserving the midline supraspinous ligament, an osteotome was used to strip muscle attachments from the lateral aspects of the spinous processes and enable stabilisation of the vertebral arch lamina (usually 6 to 13 in total). For the spinal segmental fixation with pins and wires (Figs. 3a,b), Steinmann pins of diameters appropriate to dog size were selected and drilled through, or passed around, the spinous process of the most caudal and/or cranial vertebra to be included in the fixation. The distal end of the pin was then bent at 90 ° using wire holders, so that the remaining part of the pin was parallel to the remaining spinous processes to be included in the fixation. Two Steinmann pins were used in five dogs (1, 2, 3, 4 and 7) and one Steinmann pin was used in two dogs (5 and 6). In two dogs (8 and 9), a U-shaped Steinmann pin was used, with the bend anchored through the spinous process of the most caudal or cranial vertebra to be included in the fixation.

More precisely, in dog 1, the cranial ends of both pins were passed around the spinous process of C7, the caudal end of the left pin was drilled through the spinous process of T12 and the caudal end of the right pin ended at T12 but was not anchored. In dog 2, the cranial end of the right pin was passed around the spinous processes of T1; the cranial end of the left pin was drilled through the spinous process of T2; the caudal end the left pin was drilled through the spinous process of T13, and the caudal end of the right pin was passed around the spinous process of T12. In dog 3, the cranial ends of both pins were passed around the spinous process of C7; the caudal end of the left pin was passed around the spinous process of T10, and the caudal end of the right pin was drilled through the spinous process of T11. In dog 4, the cranial ends of both pins were drilled through (left pin) or passed around (right pin) the spinous process of T3, and the caudal ends of both pins were drilled through (right pin) or passed around (left pin) the spinous process of L1. In dog 7, the cranial ends of both pins were passed around the spinous process of C7, and the caudal ends of both pins were drilled through the spinous process of T10. In dogs 5 and 6, the ends of the pin were drilled through the spinous process of T2 (cranial end, dog 5) or T5 (cranial end, dog 6) and T10 (caudal end, dog 5) or L1 (caudal end, dog 6). In dogs 8 and 9, the pin was passed through the spinous process of T1 (dog 8) or T10 (dog 9), forming a U-shape at that level, with the two ends extended caudally up to the level of the spinous process of T10 (dog 8), or cranially up to the level of the spinous process of T3 (dog 9).

Sutures (orthopaedic wire or polypropylene) were placed through each spinous process lying parallel to the Steinmann pin and used to secure the pin to the spinous processes in sequence. The size of the Steinmann pin varied between 1.1 and 2 mm and the size of the orthopaedic wire ranged from 0.45 to 0.8 mm; in two cases (8 and 9), 4 metric polypropylene (Prolene, Ethicon) was used in combination with orthopaedic wire.

A partial lateral corpectomy, combined with a mini-hemilaminectomy, was also performed at T8-T9 in dog 4, before segmental stabilisation. A dorsal laminectomy was performed at T7-T8 (dog 9) and T8 (dog 8).

Immediate post-operative radiographs showed correct positioning of the implants. Analgesic drugs were given 4 -13 days post-operatively, with a mean duration of 8 days (range 1-14 days).

Outcome

Details of the outcome of each case are provided in Table 3. All dogs showed improvement in neurological status in the immediate post-operative period and the mean time of hospitalisation and improvement following surgery was 6 days (range, 1 - 14 days). In two dogs, initial post-operative deterioration occurred (Table 3), but the gait subsequently improved spontaneously within 11 days (dog 2), or following repetition of surgery (dog 8).

A first post-operative recheck was performed within the first 6 months post-operatively in all dogs apart from dogs 5 and 8. These examinations were performed at 1 month (1, 2, 3 and 6), 2 months (7 and 9), 3 months (9) and/or 6 months (4 and 9) post-operatively. At examination, all dogs were ambulatory, with improved gait and improved hind limb postural reactions compared to the initial presentation (Table 3). Spinal hyperaesthesia was absent and all dogs had urinary and faecal continence.

A final recheck was performed between 1.5-5.5 years post-operatively in all dogs, i.e. at 1.5 years (5, 6 and 7), 2 years (1, 3 and 4), 3 years (2), 4.5 years (8) and 5.5 years (9) post-operatively. All owners reported satisfaction with their dog's gait, describing it as a normal (1, 3, 5 and 7) or an intermittently mildly uncoordinated gait (2, 4, 6, 8 and 9). None of the dogs showed evidence of pain and all retained urinary and faecal continence. On neurological examination, four dogs were neurologically normal (1, 3, 5 and 7), four dogs showed a very mild hind limb ataxia (2, 4, 6 and 9), and one dog had a moderate degree of paraparesis (dog 8; Table 3).

Immediate (8) or delayed (1 and 2) post-surgical complications were reported in three dogs. Dog 8 became paraplegic and lost urinary continence but retained intact deep pain sensation 5 days following surgery. Spinal radiographs and CT-scans showed that one of the pins was encroaching into the thoracic vertebral canal and causing spinal cord compression. Surgery was repeated and the pins were replaced by a single, larger implant, resulting in a gradual improvement. Follow-up radiographs 3 months later showed a broken pin and, although financial constraints precluded a repeat surgery to remove the pin, the dog remained neurologically stable, with moderate ambulatory paraparesis.

Dog 1 presented with thoracolumbar spinal pain 2 years post-operatively. Spinal radiographs showed implant loosening where the caudal end of the Steinmann pin was previously placed through the spinous process. Surgery was not performed and the pain resolved spontaneously after rest. Dog 2 re-presented 3.5 years post-operatively with deterioration of the pelvic limb gait. Spinal radiographs showed osteolysis at the base of the spinous processes around the pin, resulting in implant loosening. An offer of repeat surgery was declined and the dog remained clinically affected, with severe ambulatory paraparesis.

Discussion

This is the first case series to describe the use of spinal segmental stabilisation with Steinmann pins and orthopaedic wires and/or polypropylene sutures in dogs with hemivertebrae. Spinal segmental stabilisation has been reported only once in a dog with hemivertebrae, but with a relatively short follow-up time of 3 weeks (Jeffery et al., 2007).

Clinical signs of hemivertebrae in dogs usually are not present at birth, but occur during youth (< 1 year old; 60% of reported cases) or adulthood (>1 year old; 40% of reported cases; Aikawa et al., 2007; Jeffery et al., 2007; Meheust and Robert, 2010). These proportions are similar to the group in this study.

In dogs, it is generally believed that neurological signs associated with hemivertebra might improve once vertebral column growth ceases at approximately 9 months (Jeffery et al., 2007), and that surgery might therefore not be needed if clinical signs are not severe by that time. Although this has not been thoroughly investigated, many of the dogs in the current study, both immature and adults, experienced chronic progression of neurological signs. This is similar to other reports and suggests that, at least in a proportion of affected dogs, surgery might be needed (Aikawa et al., 2007; Jeffery et al., 2007; Meheust and Robert, 2010). In children, early surgery is performed, because vertebral malformations and spinal malalignment worsen during skeletal growth and can result in spinal cord injury (Philips et al., 1997; Kim et al., 2001; McMaster and Singh, 2001) , although such surgery is also often performed for cosmetic, rather than neurological, reasons.

The pins of the spinal segmental stabilisation technique perhaps act as an internal brace, preventing further vertebral column malangulation in immature dogs and minimising further spinal cord injury due to instability in adult dogs. Moreover, fixation with Steinmann pins and orthopaedic wires and/or sutures is considered a relatively safe and easy technique when compared to other stabilisation methods, with minimal risk of iatrogenic damage to the spinal cord compared to the placement of pins within malformed vertebral bodies. In one of the cases of this study, however, in an attempt to place the Steinmann pin as ventrally as possible at the base of the spinous processes, entry into the vertebral canal occurred, requiring removal and replacement of the implant. In addition, using this technique, there is no need for PMMA, which can increase the risk of post-operative infection (Matthiesen, 1983).

Spinal cord dysfunction in dogs with hemivertebrae could be caused by either compression or instability, or a combination of both. The primary goal of surgical treatment in the current study was stabilisation. Even in cases with severe vertebral canal stenosis that did not have decompressive surgery, a satisfactory outcome was reached. Although our dataset is too small to make firm conclusions, this finding is similar to other veterinary studies reporting no obvious difference between cases treated with stabilisation, with or without decompression (Aikawa et al., 2007; Jeffery et al., 2007). This could support the view that vertebral stabilisation is an important factor in clinical outcome.

In one case described this study, a partial lateral corpectomy was performed as a decompression technique. In the other two cases where decompression was performed, dorsal laminectomy was used. Partial lateral corpectomy is theoretically preferable to dorsal laminectomy or hemilaminectomy, since it alleviates ventral spinal cord compression more completely and avoids further disruption to supraspinous structures that might maintain stability. In humans, dorsal laminectomy is considered contraindicated in cases with kyphosis, because removal of the dorsal bony structure might result in more rapid progression of the kyphosis and greater ventral spinal cord compression (Winter, 1977). However, a recent veterinary report describes a cat with hemivertebra associated with kyphosis and a successful outcome following dorsal laminectomy alone (Havlicek et al., 2009).

In humans, treatment of hemivertebrae is challenging and the choice between surgical techniques is controversial. It is thought that severe deformity can be prevented if the patient is treated prophylactically at an early age by a spine fusion maintained dorsally (Moe et al., 1984;

Akbarnia et al., 2005). Delayed treatment requires additional ventral osteotomy in order to re-align the spinal column, which is more difficult and potentially more hazardous (Winter et al., 1973; McMaster and Singh, 2001). A transthoracic approach with a partial ventral corpectomy has been attempted in one Labrador puppy (Meheust and Robert, 2010). Based on experience in human surgery we could speculate that early treatment with a dorsal fixation technique in dogs with kyphosis might avoid a more hazardous procedure. However, dog selection for such a procedure would be fraught with difficulty, because most dogs that have hemivertebrae are subclinical throughout their whole life (Done et al., 1975; Bailey and Morgan, 1992; Jeffery et al., 2007; Meheust and Robert, 2010; Moissonnier et al., 2011).

Dogs with paraparesis and hemivertebrae might have neurological signs that are not solely related to spinal cord injury through vertebral canal stenosis or instability. Vertebral malformations have been reported to occur alongside other congenital or acquired spinal or spinal cord anomalies (Parker et al., 1983; Shell et al., 1988; Ruberte et al., 1995; Moissonnier et al., 2011). In one dog described in the present study, a concurrent syrinx was present and two dogs had disc protrusions. Microscopic spinal cord abnormalities, not visible on MRI, cannot be excluded in these cases.

Although all dogs improved following surgery and all owners were satisfied with the final outcome, approximately half of the dogs had a residual ataxic gait. This might have been due to persistent spinal cord compression, but could also have been caused by unidentified concurrent spinal cord malformations and/or irreversible chronic damage of the nervous tissue before surgery. This incomplete recovery has been also observed in previous studies (Aikawa et al., 2007; Jeffery et al., 2007; Meheust and Robert, 2010).

Although spinal segmental stabilisation is a relatively simple technique, complications were not uncommon in this case series. Immediate post-operative complications occurred in one dog and delayed post-operative complications were reported in two dogs, in one of which the Steinmann pin broke and had to be replaced; this possible complication has previously been reported after using spinal segmental stabilisation for spinal fractures (Cage, 1973; Matthiesen, 1983; Mcanulty et al., 1986). One dog showed worsening of neurological signs due to pressure necrosis of the spinous processes and implant loosening. Demineralisation of spinous processes has been previously reported following the use of plastic (Lubra) plates on the spinous processes (Krauss et al., 2012). One dog manifested temporary pain due to mild implant loosening, but this resolved spontaneously. A possible disadvantage of this technique is the large exposure required to place the implants over a sufficient distance to achieve adequate stabilisation.

Conclusions

This case series reports a spinal segmental stabilisation technique that is a valid option for treating small dogs with dorsal hemivertebrae and kyphosis. Although the final outcome was good to excellent in most cases, immediate or delayed post-operative complications were common. Further adaptations, particularly those designed to prevent implant loosening, for example by promoting bony fusion, might overcome these complications. Multi-centre studies with larger numbers of dogs are needed in the future to determine the optimum surgical techniques in both immature and mature dogs.

Conflict of interest statement

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

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Figure legends

Fig. 1. Lateral view of the thoracic vertebral column of dog 4. Thoracic dorsal hemivertebrae at T8 and T9 (arrows). Marked kyphosis centred at T7-T9. Vertebral column malangulation was measured with the aid of the modified Cobb angle (angle between the two lines).

Fig. 2. Sagittal T2-weighted MR image of the thoracolumbar vertebral column of dog 8. Thoracic dorsal hemivertebra at T8 (arrow). Marked kyphosis at T5-T8. Note the degree of vertebral canal height reduction at the site of the hemivertebra.

Fig. 3. Lateral (a) and dorsoventral (b) view of the thoracic vertebral column of dog 3 post-operatively. Thoracic dorsal hemivertebrae at T7 and T8 (arrows). The cranial ends of both pins were passed around the spinous process of C7, the caudal end of the left pin was passed around the spinous process of T10 and the caudal end of the right pin was drilled through the spinous process of T11. Orthopaedic wires (0.45 – 0.62 mm) were passed through predrilled holes in each spinous process of C7-T11 vertebra and are twisted to secure the pins to the vertebral processes.

Table 1 Graded scale of ataxia and paraparesis

Grade	Neurological status characterisation	Gait description, including neurological deficits
0	Neurologically normal	Normal gait. No neurological deficits.
1	Mild and inconsistent ataxia	Gait seems to be normal most of the time, but occasional crossing of the pelvic limbs can occur. Subtly delayed postural reactions in one or both pelvic limbs.
2	Mild and consistent ataxia	Mildly uncoordinated gait with frequent crossing of the pelvic limbs. Delayed postural reactions in one or both pelvic limbs.
3	Moderate ambulatory paraparesis	Markedly uncoordinated gait with frequent crossing and dragging in one or both pelvic limbs and occasional pelvic limb collapse. Markedly delayed postural reactions in one or both pelvic limbs.
4	Severe ambulatory paraparesis	Severely incoordinated gait with frequent crossing and dragging pelvic limbs and frequent pelvic limb collapse. Severely delayed or absent postural reactions in one or both pelvic limbs.
5	Non-ambulatory paraparesis	Permanent pelvic limb collapse, with voluntary movement in both limbs but inability to walk without support. Markedly delayed or absent postural reactions.

Table 2 Clinical details of nine cases with hemivertebra(e)
F, female; M, male; N, neutered; SSF, spinal segmental fixation;

Dog number	Breed	Age at presentation	Gender	Age of onset	Duration: Onset to presentation	Hemi-vertebra(e)	Cob's angle	Vertebral canal height reduction	Duration: Presentation to surgery	Surgery
1	Pomeranian	9 months	M	7 months	2 months	T5-6	68.1 °	88%	8 days	SSF
2	Pug	3 years 7 months	FN	3 years 6 months	2 weeks	T5-7	42.2 °	82%	3 days	SSF
3	Pug	7 months	F	7 months	4 days	T7-8	30.5 °	62%	2 months	SSF
4	English bulldog	9.5 months	FN	7 months	2 months	T8-9	45 °	72%	10 days	SSF, corpectomy
5	Pug	6 years 10 months	MN	6 years 7 months	3 months	T7-8	20 °	78%	12 days	SSF
6	English bulldog	6 years 5 months	F	6 years 5 months	1 days	T4-9, T11	10 °	27%	1 days	SSF
7	Pug	6 months	F	5.5 months	3 weeks	T5-8	51.3 °	50%	3 weeks	SSF
8	Pug	7 months	M	6 months	1 months	T8	28.6 °	58%	1 days	SSF, dorsal laminectomy
9	Pug	2 months	M	2 months	5 days	T7-8	19.8 °	64%	1 days	SSF, dorsal laminectomy

Table 3. Neurological status before and after surgery

Dog	Neurological status before surgery	Time until discharge	First post-operative recheck (1-6 m)	Second post-operative recheck (1.5-5.5 years)
1	Grade 3 Incontinence	4 days	Grade 2	Grade 0 Complication at 2 years post operatively: Temporary cervical pain but this resolved after rest.
2	Grade 3 Spinal pain, Incontinence	11 days	Grade 2 Initially deteriorated immediately after surgery; temporary grade 3 but improved within 11 days	Grade 1 until 3.5 years post-operatively. Complication at 3.5 years post-operatively: implant loosening, grade 4.
3	Grade 5 Spinal pain, Incontinence	11 days	Grade 2	Grade 0
4	Grade 4 Incontinence	3 days	Grade 3	Grade 2
5	Grade 3	1 days	Grade 2	Grade 0
6	Grade 4 Spinal pain	1 days	Grade 3	Grade 2
7	Grade 3	5 days	Grade 3	Grade 0
8	Grade 4 Incontinence	14 days	Grade 3 Initially deteriorated 5 days after surgery. The dog was temporarily paraplegic with intact deep pain and incontinent until removal and replacement of implants	Grade 3
9	Grade 5	7 days	Grade 4	Grade 1