Equine Veterinary
Education

EQUINE VETERINARY EDUCATION
Equine vet. Educ. (2018) •• (••) ••-••
doi: 10.1111/eve.12980

Original Article

Unexplained forelimb lameness possibly associated with radiculopathy

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Keywords: horse; diagnostic analgesia; radiography; cervical vertebrae; neuropathic pain

Summary

There are limited descriptions of forelimb lameness that is not improved by diagnostic analgesia. The objectives of this retrospective study were to describe the clinical features, response to diagnostic analgesia and imaging findings in such horses (n = 25), to apply a ridden horse ethogram to video recordings of a subset of horses (n = 13) and to document post-mortem findings (n = 3). Clinical records from 2006 to 2016 were reviewed, and data concerning signalment, history, lame limb(s), lameness characteristics, response to diagnostic analgesia and diagnostic imaging were recorded. A ridden horse ethogram was applied to 13 horses to document pain-related behaviour. Results showed that nine horses had idiopathic hopping-type forelimb lameness only when ridden; two horses exhibited a hopping-type gait only on the lunge or worse on the lunge than ridden, and 14 horses had conventional lameness. Head and neck tilt was observed in 24% of horses. Lameness was different on a long rein compared with a contact in 28% of horses. Forelimb stumbling was a feature in 16% of horses. Exacerbation of lameness by diagnostic analgesia was seen in 76% of horses. Radiographic abnormalities of the caudal cervical and cranial thoracic vertebrae of potential clinical significance were observed in 92% of horses. Pain behaviour scores were higher than those reported for nonlame horses. Post-mortem examination of three horses provided the evidence of caudal cervical or cranial thoracic nerve root compression. Limitations of the study were that it cannot be assumed that there was a common aetiology of lameness in all horses. It was concluded that there is increasing evidence that nerve root injury may cause forelimb lameness.

Introduction

There are limited reports of forelimb lameness attributable to primary neck pain. Eight horses were described with forelimb lameness which did not respond to diagnostic analgesia of the forelimb, with evidence of neck pain or stiffness or muscle atrophy and which had marked radiological abnormalities of the caudal cervical and cranial thoracic vertebrae considered likely to have an association with pain (Ricardi and Dyson 1993). One horse had post-mortem evidence of cervical nerve root pathology. An additional ten horses with similar clinical features associated with severe osteoarthritis of the articular process joints between the fifth cervical and first thoracic vertebrae were documented briefly (Dyson 2011a), including one horse with discospondylitis between the seventh cervical and first thoracic vertebrae.

Idiopathic hopping-type forelimb lameness syndrome in ridden horses has been described, typified by elevation of the head and neck as the lame limb was protracted (Dyson and Rasotto 2016). It was suggested that there may be an association with caudal cervical or cranial thoracic nerve root pathology based on histological abnormalities in a limited subset of horses. Affected horses had lameness that was generally only seen ridden and was typified by varying severity and frequency of hopping-type steps. When lameness was at its worst, horses were reluctant to go forwards and had facial expressions and behaviour suggestive to the authors of pain (Dalla Costa *et al.* 2014; Gleerup *et al.* 2015; Dyson *et al.* 2017a,b, 2018). In 39% of horses, the lameness was markedly influenced by the position of the head and neck. A small proportion of horses (7%) had a tendency to stumble. Lameness was characterised by deterioration following a variety of diagnostic analgesic techniques in more than one-third of horses. Lameness was consistently unresponsive to nonsteroidal anti-inflammatory analgesic drugs. Peer reviewers had expressed scepticism about pain being the underlying cause of lameness.

The purposes of this study were to (1) describe a horse which exhibited a similar hopping-type forelimb lameness on the lunge (as described by Dyson and Rasotto 2016), but not ridden, with definitive evidence of caudal cervical and cranial thoracic nerve root injury on both gross post-mortem examination and histopathology; (2) describe the clinical and diagnostic imaging features of a further ten horses with idiopathic hopping-type forelimb lameness and 14 horses with unexplained forelimb lameness which shared some similar clinical and radiological features; and (3) document the results of the application of an ethogram for ridden horse behaviour.

Materials and methods

Horses with idiopathic hopping-type forelimb lameness when ridden (n = 9) (Group 1) or hopping-type forelimb lameness seen only on the lunge (n = 1) or more on the lunge than ridden (n = 1) (Group 2) that were presented for investigation in 2015 and 2016 were reviewed, in addition to 14 horses with unexplained forelimb lameness which were examined between 2006 and 2016 (Group 3). None of the horses had substantial improvement in forelimb lameness after diagnostic analgesia. Diagnostic techniques were applied to all horses (n = 25), except when stated otherwise. All horses were evaluated at the Animal Health Trust by an experienced clinician (Royal College of Veterinary Surgeons Specialist in Equine Orthopaedics) and a comprehensive clinical assessment was performed, including palpation and manipulation of the limbs and trunk, and other diagnostic techniques as detailed below. Neck flexibility was assessed using baited stretch exercises. Horses were evaluated moving in hand at walk (including small circles) and trot, on the lunge on left and right reins on both soft and firm surfaces, and ridden. Horses were assessed ridden by the usual rider and by an Animal Health Trust technician, both ridden to a contact (with rein tension) and on a long rein (without rein tension) and sitting on both the left and right diagonals at rising trot. Horses were assessed at walk, trot and canter both on the lunge on a soft surface and when ridden. Examinations were repeated on several occasions to assess the consistency of clinical features. Lameness characteristics were documented, and the lameness was graded on a scale of 0–8 (0 = sound; 2 = mild; 4 = moderate; 6 = severe; 8 = nonweightbearing) (Dyson 2011b). The presence of stumbling was recorded. A comprehensive neurological assessment was performed in all horses.

Diagnostic analgesia was performed in all lame limbs, with a minimum of perineural analgesia of the palmar (base of proximal sesamoid bones) nerves and the median and ulnar nerves, and intra-articular analgesia of the scapulohumeral and humeroradial joints in the lame(r) forelimb (Bassage and Ross 2010). Ultrasound-guided intra-articular analgesia of caudal cervical articular process joints (up to 10 mL mepivacaine) was performed in six horses. Diagnostic analgesia was not performed in four horses, two with episodic root signature posture (Horses 24 and 25, **Table 1**), one with an obvious gait abnormality at the walk (only recently broken) (Horse 16) and one horse in which hopping-type forelimb lameness temporarily resolved spontaneously (Horse 6).

Video recordings of approximately 5 minutes' duration of 13 horses (6, 1 and 6 from Groups 1, 2 and 3, respectively) were available for retrospective analysis and application of a ridden horse ethogram to determine a pain behaviour score (0–24) (Dyson *et al.* 2017b, 2018) (see **Supplementary Item 1**). Footage had been acquired after other concurrent sources of pain contributing to poor performance had been abolished by diagnostic analgesia. Video recordings were all assessed in real time, but could be stopped and replayed. All scoring was performed by a single, trained assessor.

Radiographic examination of the cervical and cranial thoracic vertebrae (lateral–lateral images and right ventral-left dorsal and left ventral-right dorsal oblique images), the scapulohumeral joint (mediolateral [extended] and craniomedial-caudolateral oblique [extended] images), the humeroradial-ulnar joints (mediolateral [extended] and craniocaudal), the sternum (lateral–lateral) and cranial ribs (lateral–lateral) was performed (Butler *et al.* 2017). For acquisition of the cervical radiographs, the horses stood in stocks, with the head supported on a headstand in a neutral position. There was a fixed focus imaging plate distance, with the imaging plate as close to the horse as possible. The radiographs of the cervical and cranial thoracic regions were reassessed qualitatively (Mayhew *et al.* 1993; Down and Henson 2009), blindly and in random order. Quantitative measurements for calculation of intravertebral and intervertebral sagittal ratios were acquired for the third to seventh cervical and first thoracic vertebrae using Easy Image[1] .

Nuclear scintigraphic examination of the cervical and thoracic regions (from right to left and from left to right), forelimbs, sternum and ribs was performed in four horses. Bone phase images were acquired dynamically over two minutes using a 128 × 128 matrix, 53 × 39 cm field of view gamma camera and general purpose collimator, 2–2.5 h after injection of ^{99m}technetium methylene diphosphonate (1 GBq/100 kg bodyweight). A motion correction programme was used to obtain static images (Hermes[2]). Ultrasonographic assessment of the caudal neck region, shoulder and elbow regions was performed using a variable frequency (8–12 MHz) linear array or virtual convex array transducer (LOGIQ e[3]) in all horses.

Three horses were examined post-mortem. In addition to gross inspection of the joints, multiple muscle sections and the brachial plexus of both forelimbs, the cervical and cranial thoracic spinal cord and nerve roots were dissected. The spinal cord was inspected, sectioned in segments (C1-C2½, C2½-C3½, C3½-C4½, C4½-C5½, C5½-C6½, C6½-T2½) and its consistency assessed by palpation. Samples from each segment of spinal cord and nerve roots were collected for histology. Sections were stained with haematoxylin and eosin. Cervical and cranial thoracic vertebrae and the first ribs were examined after boiling out and cleaning.

Results

Signalment and history

The key to horse numbers is in **Table 1**, and signalment of all horses is summarised in **Table 2**. One horse in Group 1 (Horse 3) had a history of trauma: three unexplained falls. Two horses (Horses 1 and 2) had performed poorly since purchase, for 2 years and 9 months, respectively. Five additional horses were presented for poor performance (Horses 7, 13, 14, 21 and 23). Three horses were reluctant to go forwards freely (Horses 8, 9 and 11). Three horses had developed abnormal tension during ridden work (Horses 3, 6 and 22). One horse was presented because of a change in jumping performance (Horse 4). One horse reared dangerously (Horse 24) and one bolted (Horse 10). Two horses had developed a head tilt (Horses 15, 22). One horse was specifically presented because of a hopping-type forelimb lameness (Horse 5). Seven additional horses were presented for forelimb lameness investigation (Horses 12, 16, 17, 18, 19, 20 and 25).

Clinical features

Clinical features are summarised in **Table 3**. Four horses had limited lateral neck flexibility (Horses 11, 16, 22 and 24). There was generalised atrophy of the caudal neck muscles in four horses (Horses 19, 22, 23 and 25). One horse (Horse 14) was hyperreactive to light pressure applied with mosquito forceps to the right caudal neck region, ipsilateral to the lame forelimb. One horse (Horse 25; **Fig 1**) showed marked muscle spasm and pain with light digital palpation of the caudal aspect of the left side of the neck, ipsilateral to the lame forelimb, only when showing root signature posture. Three horses had forelimb lameness in hand (Horses 17, 18 and 20); one additional horse showed a short-stepping forelimb gait (Horse 19). Lameness was apparent on the lunge in eight horses (Horses 6 [occasional mild hop on one rein, **Supplementary Item 2**], 10 [hopping-type left forelimb lameness only on the left rein on a soft surface; the head carriage was consistently unsteady on the left rein], 11 [hopping-type right forelimb lameness on both reins on a soft surface], 17, 18, 20 [decreased height of arc of foot flight and shortened cranial phase of the step of the lame forelimb], 22

TABLE 1: Summary of the lame limb(s), worst grade of lameness (0–8), the presence of stumbling, whether lameness was accentuated by diagnostic analgesia of the lame limb and radiological features in 25 horses with forelimb lameness unresponsive to diagnostic analgesia. Group 1 = idiopathic hopping-type forelimb lameness only seen ridden (n = 9); Group 2 = idiopathic hopping-type forelimb lameness only apparent on the lunge or worse on the lunge than ridden (n = 2); Group 3 = other unexplained forelimb lameness (n = 14). Lameness was worst when ridden, except when stated otherwise

	Horse number	Lame limb(s) and worst degree of lameness	Lameness worse after diagnostic analgesia	Radiological features
Group 1	1	LF 6	+	Moderately enlarged APJs C67; dorsoventrally narrowed IVF
	2	RF 4	+	Markedly enlarged APJs C56 and 67, R>L; ventral buttressing C56 and 67; partial occlusion of IVF
	3	RF 5	+	Moderately enlarged APJs C56 and 67; dorsoventrally narrowed IVF; wedge-shaped vertebral canal C6 and 7
	4	RF 5	–	Markedly enlarged APJs C67 and C7T1 and narrow IVF; short pedicles C4–6; wedge-shaped vertebral canal C7
	5	RF 6	+	Short pedicles C3–7; low slung APJs and narrow IVF; APJ C67 slightly enlarged; wedge-shaped vertebral canal C6
	6	RF 5	NA	Moderately enlarged APJs C56 and 67 and C7T1; ventral buttressing C56 and 67; short pedicles and small IVF
	7	RF 5	–	Moderately enlarged APJs C56 and 67 and C7T1; ventral buttressing C56 and 67; short pedicles and small IVF; wedge-shaped vertebral canal C6 and 7
	8	LF and RF 6	+	Massive enlargement of APJs C67 with ventral buttressing; partial occlusion of IVF; wedge-shaped vertebral foramen C6 and 7
	9	RF 6	+	NAD
Group 2	10	LF 4 only on lunge	+	Subluxation C7T1 with dorsal displacement of the head of T1; wedge-shaped vertebral canal C7; narrow IVF C67; spur ventrocaudal aspect C6
	11	RF 6 Stumbled	+	Short pedicles and therefore low slung APJs with small IV foramina C4–6; mild enlargement of APJ C67 and narrow IVF
Group 3	12	LF 4	–	Severe enlargement of APJs C56 and 67 and ventral buttressing with occlusion of IVFs; wedge-shaped vertebral canal C6 and 7
	13	LF 4	+	Spurs ventral aspect of APJs C56; enlargement and ventral buttressing of APJs C67 and C7T1; narrowed IVFs; spur caudoventral aspect of vertebral body C6; transposition of ventral processes to C7; wedge-shaped vertebral canal C6 and 7; caudal extension of dorsal lamina of C5 and C4; caudal epiphyseal flare C6 and 7; intravertebral sagittal diameter ratio ≤0.48 C6 and 7
	14	RF 5	+	Moderate enlargement of APJs C67 with ventral buttressing; narrowed IVF; wedge-shaped vertebral canal C6; intravertebral sagittal diameter ratio ≤0.48 C6
	15	LF 2 Stumbled	+	Mild subluxation C7T1. Asymmetrical enlargement of APJs C7T1 > C67, R>L; ventral buttressing; narrowed IVF; transposition of ventral processes from C6 to C7
	16	LF 5 Stumbled	NA	Short pedicles C3–6 so low slung APJs and narrowed IVF; moderate enlargement of APJs C45 and 56; marked enlargement of APJs C67 and C7T1 with ventral buttressing and partial occlusion of IVFs; wedge-shaped vertebral canal C6 and 7
	17	RF 3	+	NAD
	18	LF 4 on lunge	+	Moderately enlarged APJs C67 with narrow IVF
	19	LF>RF 2 Stumbled	+	Moderately enlarged APJs C7T1 with dorsoventral narrowing of IVF
	20	RF 4 on lunge	–	Marked enlargement of APJs C56, 67 and C7T1, with ventral buttressing C56 and 67 and occlusion of IVF; small IVF C7T1; wedge-shaped vertebral canal C6 and 7
	21	LF 4 at walk to contact	–	Osseous fragments on dorsocaudal aspect of vertebral body of C5; mild symmetrical enlargement of APJs C6/7; narrowed IVF C67; wedge-shaped vertebral canal C6 and 7

TABLE 1: Continued

Horse number	Lame limb(s) and worst degree of lameness	Lameness worse after diagnostic analgesia	Radiological features
22	RF 3 on lunge	+	Short pedicles and low slung APJs C3–6 and small IVFs; mild enlargement of APJ C56 and ventral buttressing with partial occlusion of IVF; marked enlargement of APJs and ventral buttressing with partial occlusion of IVF C67; wedge-shaped vertebral canal C6; caudal extension of dorsal lamina of C4, 5 and 6; intravertebral sagittal diameter ratio ≤0.48 C5, 6 and 7
23	RF 4	+	Short pedicles and therefore low slung APJs with small IV foramina C4–6; moderate enlargement of APJ C56; very marked enlargement APJ C67 and ventral buttressing R>L; wedge-shaped vertebral canal C6 and 7; caudal extension of dorsal lamina of C5, 6 and 7; dorsal displacement of head of T1
24	RF 8* on lunge	NA	Very mild subluxation C34; marked enlargement of APJs C45, 56, 67 and C7 T1 with ventral buttressing and occlusion of IVFs; caudal epiphyseal flare C5 and 6; transposition of modified ventral processes to C7
25	LF 8*	NA	Moderate enlargement of APJs C56 and narrowed IVF; moderate enlargement of APJs C67 with ventral buttressing and occlusion of IVF; wedge-shaped vertebral canal C6 and 7, narrowed cranially; spur caudoventral aspect C6

*Sporadic root signature; no baseline forelimb lameness seen. RF, right forelimb; LF, left forelimb; NA, not applicable; NAD, no abnormality detected; APJ, articular process joint; IVF, intervertebral foramen; C, cervical vertebra; T, thoracic vertebra; R, right; L, left.

[only on a firm surface with the lame forelimb on the inside], 23 and 24 [episodic root signature, but no baseline forelimb lameness although the neck was held stiffly; grunted; elevated respiratory rate relative to the amount of work]). Two additional horses exhibited a concurrent forelimb lameness on the lunge which was abolished by distal limb nerve blocks (Horses 2 and 13); this did not alter the forelimb lameness seen when ridden.

Six horses in Group 1 (Horses 1, 2, 3, 6, 7 and 9), one horse in Group 2 (11) and six horses in Group 3 (Horses 12, 13, 14, 15, 21 and 22), respectively, exhibited concurrent hindlimb lameness when ridden. Abolition of hindlimb lameness by diagnostic analgesia did not improve the forelimb gait in any horse. Hopping-type lameness or other forelimb lameness was only seen ridden after hindlimb lameness was abolished in one horse in Group 1 (Horse 7) and 3 horses in Group 3 (12, 15 and 22). Forelimb lameness deteriorated after hindlimb lameness was abolished by diagnostic analgesia in four additional horses, two each in Groups 1 (Horses 3 and 9) and three (Horses 13 and 14), respectively.

Forelimb lameness was apparent when ridden in all horses in Group 1, one horse in Group 2 and 13 of 14 horses examined ridden in Group 3 (excluding Horse 24). Lameness was only evident in collected trot and not working trot in Horse 13. Horse 21 only showed forelimb lameness at walk to a contact, characterised by a shortened cranial phase of the step. Horse 25 showed episodic root signature posture, with the head and neck turned slightly towards the lame limb, but no baseline forelimb lameness (**Fig 1**). One horse (Horse 22) with a variable degree of head and neck tilt only showed forelimb lameness when ridden on a long rein. Paradoxically, the horse did not tilt its head when on a long rein. Horse 10 showed no lameness but was difficult to turn, evasive and hung (had increased rein tension) on the left rein (ipsilateral to the forelimb with a hopping-type lameness on the lunge).

Overall nine horses had left forelimb lameness, 14 horses had right forelimb lameness and two horses had bilateral forelimb lameness. In Group 1, the worst degree of lameness ranged from grades 4 to 6 (median 5); in Group 2, the worst lameness grade was 6 (on the lunge) and in Group 3 the worst degree of lameness ranged from 2 to 6 (median 4), excluding the two horses with episodic root signature posture. Horses 10 and 11 (Group 2) and two horses in Group 3 (Horses 20 and 22) showed the worst grade of lameness when lunged compared with ridden exercise (**Table 1**).

Five horses, one in Group 1 (Horse 4) and four in Group 3 (Horses 15, 16, 21 and 22) exhibited a tilt of the head and neck when ridden (**Fig 2**), but not in hand or on the lunge, including two horses lame at the walk (Horses 16 and 21). In all horses, the nose was tipped to the opposite direction of the lame limb when ridden (i.e. if the horse showed left forelimb lameness, the nose tipped to the right) (**Fig 2**). However, the two horses with episodic root signature posture tipped the nose slightly towards the lame limb when exhibiting clinical signs, standing still (**Fig 1**). In two horses (Horses 15 and 22), the head and neck tilt was consistently worse in canter than trot. Three horses (Horses 10, 15 and 22) hung heavily on one rein. One horse in Group 1 (Horse 6, right forelimb lameness ridden) had a head tilt on the lunge on the right rein, with the nose to the left (**Supplementary Item 2**).

Three horses in Group 1 (2, 4 and 8), one horse in Group 2 (Horse 10) and two horses in Group 3 (14, 22) episodically threw their head upwards and often to one side. One horse in Group 2 (11) and three horses in Group 3 (15, 16 and 19) intermittently stumbled in front on either the lame or the nonlame limb. Reluctance to go forwards freely, even after concurrent lameness resolved, was shown by seven horses in Group 1 (1, 2, 4, 5, 6, 8 and 9) (**Fig 3** and **Supplementary Item 3**), one horse in Group 2 (11) and seven horses in Group 3 (12, 13, 16, 17, 23, 24 and 25), usually corresponding to when the forelimb lameness was most severe.

In seven horses, there was a marked change in lameness when the horse was ridden on a long rein compared with a

TABLE 2: Signalment of all horses with forelimb lameness unresponsive to diagnostic analgesia. Group 1 = idiopathic hopping-type forelimb lameness only seen ridden (n = 9); Group 2 = idiopathic hopping-type forelimb lameness only apparent on the lunge or worse on the lunge than ridden (n = 2); Group 3 = other unexplained forelimb lameness (n = 14)

	Group 1	Group 2	Group 3
Age (years)			
Range	5–13	8–12	3–14
Median	8		7
Mean	8.0	10.0	7.5
Breed			
WBL	3	0	7
TBX	0	0	3
ISH	3	0	2
ID	1	0	0
Pony	2	1	2
QH	0	1	0
Sex			
Mare	3	0	4
Gelding	6	2	10
Height (cm)			
Range	147–168	150–157	132–169
Median	158		168
Mean	158	153	168
Bodyweight (kg)			
Range	436–670	538–560	350–690
Median	544		580
Mean	548	549	555
Work discipline			
GP	6	2	3
Eventing	1	0	5
Dressage	2	0	3
SJ	0	0	3

WBL, Warmblood; TBX, Thoroughbred cross; ISH, Irish Sports Horse; ID, Irish Draught; Pony includes Connemara; QH, Quarter horse; GP, general purpose (including unaffiliated competition); SJ, showjumping.

contact. Lameness was less obvious on a long rein in one horse (Horse 1) in Group 1 and four horses in Group 3 (Horses 12, 13, 21 [lameness was only apparent at the walk] and 25). Horse 25 only developed a root signature posture if ridden ‘on the bit’; with a less-skilled rider compared with the owner, the horse tended to work ‘above the bit’, and root signature posture was not observed. One horse in Group 1 (Horse 6) showed lameness that was consistently more obvious on a long rein than when ridden to a contact. Horse 22 in Group 3 only showed forelimb lameness on a long rein, despite an obvious head and neck tilt when ridden to a contact.

There were no consistent changes in lameness according to the diagonal on which the rider sat. However, when horses hopped severely, it felt to the rider that the horse was trying to make them change diagonal and sometimes did so.

Responses to diagnostic analgesia

Lameness deteriorated by one to three grades after one or more local analgesic techniques in six of eight horses in Group 1 (Horses 1, 2, 3, 5, 8 and 9), with or without increased frequency of hopping-type steps. Lameness deteriorated by up to three grades in both horses in Group 2 and in eight of 11 horses in Group 3 (Horses 13, 14, 15, 17, 18, 19, 22 and 23). Lameness in Horses 15 and 17 had deteriorated after preceding nerve blocks, but immediately after intra-articular analgesia of the scapulohumeral and humeroradial joints, respectively, each horse developed an obvious toe drag of the lame limb at the walk. The owner of Horse 17 had previously observed this gait occurring spontaneously. Horse 5 showed deterioration in right forelimb lameness after intra-articular analgesia of the scapulohumeral joint and then showed tilting of the head and neck with the nose to the left. Intra-articular analgesia of the articular process joints of the sixth and seventh cervical vertebrae produced improvement by one or two grades in Horses 2 and 7, respectively.

Application of a ridden horse ethogram and pain behaviour scoring

The total pain behaviour score for each horse ranged from 7 to 11/24 (most frequent 9). It was consistently observed that more pain-related behaviours were displayed when lameness was most severe. Horse 6 did not show overt lameness on the lunge, but repeatedly closed his eyes as the right forelimb (the lame limb ridden) was protracted on the right rein (**Supplementary Item 2**).

Diagnostic imaging findings

One horse in each of Groups 1 (Horse 9) and 3 (Horse 17) had no significant radiological abnormality. Horse 10 had subluxation of the seventh cervical and first thoracic vertebrae (**Table 1**, **Fig 4**). There was marked modelling of the caudal articular process joints consistent with osteoarthritis, with ventral buttressing and partial occlusion of the intervertebral foramina, in three of nine horses in Group 1 (Horses 2, 4 and 8) and in eight of 14 horses in Group 3 (Horses 12, 13, 15, 16, 20, 22, 23 and 24) (**Figs 5–8**). The articulations between the sixth and seventh cervical vertebrae (n = 10) and seventh cervical and first thoracic vertebrae (n = 6) were most commonly affected. There was moderate modelling of the caudal articular process joints with dorsoventral narrowing of the intervertebral foramina in four of nine horses in Group 1 (Horses 1, 3, 6 and 7) and four of 14 horses in Group 3 (Horses 14, 18, 19 and 25). The articulations between the sixth and seventh cervical vertebrae (n = 7) and seventh cervical and first thoracic vertebrae (n = 2) were most commonly affected.

Two horses (Horses 5 and 11) had mild enlargement of the articular process joints between the sixth and seventh cervical vertebrae; the intervertebral foramina were small dorsoventrally from the fourth to seventh cervical vertebrae inclusive. One horse in Group 3 (Horse 21) had two osseous fragments dorsocaudal to the caudal end plate of the fifth cervical vertebra. There was a small minimum sagittal diameter intravertebral ratio ($\leq$0.48) in three horses in Group 3 (Horses 13, 14 and 22) (**Table 1**). The ventral processes were transposed from the sixth to seventh cervical vertebrae in three of 25 horses (Horses 13, 15 and 24) (**Figs 6, 8**).

Ultrasonographic examination revealed focal fibrotic myopathy in two horses in Group 1 (Horses 1 [brachiocephalicus] and 5 [descending pectoral muscle]). Local infiltration of local anaesthetic solution had no effect on the lameness. Periarticular modelling of one or more articular process joints $\pm$ joint capsule thickening was observed in 15 horses, all with radiological abnormalities. Ultrasonographic abnormalities were present bilaterally in all horses; the degree of osseous modelling did not necessarily correlate with the side of the lame limb.

TABLE 3: Summary of the clinical features exhibited by 25 horses with forelimb lameness that was not improved by diagnostic analgesia of the lame limb

Clinical feature	Number of horses displaying clinical feature	%	Horse numbers*
Limited neck flexion	4	16	11, 16, 22, 24
Generalised caudal neck atrophy	4	16	19, 22, 23, 25
Hyperreactivity to neck palpation	2	8	14, 25†
Forelimb lameness in hand	4	16	17–20
Forelimb lameness on the lunge	8	32	6, 10, 11, 17, 18, 20, 22, 23, 24†
Forelimb lameness ridden	23	92	1–9, 11–23, 25
Episodic root signature	2	8	24, 25
Stumbling when ridden	4	16	11, 15, 16, 19
Shortened cranial phase of step of lame forelimb	4	16	17, 18, 20, 21
Head tilt on the lunge	1	4	6
Head tilt when ridden	5	20	4, 15, 16, 21, 22
Hopping-type forelimb lameness on the lunge	2	8	10, 11
Hopping-type forelimb lameness when ridden	9	36	1–9
Episodically tossing head upwards when ridden	6	24	2, 4, 8, 10, 14, 22
Reluctance to go forwards when ridden when lameness at its worst	15	60	1, 2, 4–6, 8, 9, 11–13, 16, 17, 23–25
Alteration of lameness when ridden with or without rein tension	7	28	1, 6, 12, 13, 21, 22, 25
Deterioration in baseline lameness after local analgesia (n = 21)	16	76	1–3, 5, 8–11, 13–15, 17–19, 22, 23

*1 = refer to Table 1 for horse identification.
† Only when showing root signature posture.

Nuclear scintigraphic examination revealed no abnormality in any of the four horses in which it was performed (Horses 5, 9, 18 and 20).

Post-mortem findings

Horse 10 had gross discoloration of the first thoracic nerve, ipsilateral to the lame forelimb and histological evidence of multifocal mild Wallerian-like degeneration with swelling and vacuolation of the myelin sheath and irregular swelling of axons. Histological examination of sections from Horse 14 revealed Wallerian degeneration with multifocal axons with loss of the myelin sheath and the presence of spheroids in the right seventh and eighth cervical and first thoracic nerves, ipsilateral to the lame forelimb. Histological examination of sections from Horse 23 revealed fibrosis of the epineurium, myelin degeneration and nerve loss, characterised by Wallerian degeneration, spheroid formation and gitter cells. These abnormalities were identified in the fourth to seventh cervical nerve roots and were worse on the left side in the fourth to sixth nerves and on the right side (ipsilateral to the lame limb) in the seventh nerve.

Fig 1: Horse 25 showing posture typical of root signature, pain associated with nerve root compression. This 12-year-old advanced event horse had episodic severe left forelimb lameness during flat work and would stop suddenly, adopting this posture. During these episodes, the horse exhibited severe pain on palpation and muscle tension over the sixth and seventh cervical vertebrae on the left side (*).

Discussion

Hopping-type forelimb lameness only on the lunge, or worse on the lunge than ridden, was observed in two horses and was associated with nerve root injury in one. In both horses, lameness on the lunge was not observed on a firm surface, only on a soft surface. In one horse, lameness was only apparent on one rein, whereas sporadic hopping was seen on both reins in the other. A hopping-type gait on the lunge or appearing to break to canter has previously been observed in association with foot pain or proximal suspensory desmitis, but has resolved with appropriate diagnostic analgesia (S. Dyson, unpublished data). A hopping-type forelimb lameness seen ridden has also been observed in association with pain in the distal aspect of the limb as the horse has tried, often successfully, to make the rider change the diagonal on which they were sitting (S. Dyson, unpublished data). However, this hopping-type forelimb lameness was abolished by diagnostic analgesia.

Lameness was only apparent at ridden walk to a contact in Horse 21. Horse 16 showed lameness characterised by a shortened cranial phase of the step at ridden walk. In addition, Horses 15 and 17 developed an obvious toe drag of the lame limb at the walk immediately after intra-articular analgesia of the scapulohumeral and humeroradial joints, respectively, a gait previously observed by the owner of Horse 17. Lameness evident in ridden walk is highly unusual, but has been observed in horses with strain of the caudal aspect of m. brachiocephalicus (Dyson 2011a). There is greater movement between the neck and trunk at the walk compared with the trot (Dunbar *et al.* 2008); the relevance of this to lameness seen at the walk is currently unknown.

Head and neck tilt was a feature identified in six horses (24%) either ridden or on the lunge. Tipping the head to one

***Fig 2:** Horses 15 a) and 22 b). Horse 15, a 6-year-old showjumper with left forelimb lameness, tilts the head and neck with the nose to the right. This was consistently worse on the left rein, although left forelimb lameness was only detectable on the right rein. The head and neck tilt was worse in canter than trot. Horse 22, a 9-year-old event horse with right forelimb lameness, is above the bit and tips the nose to the left and turns the head and neck to the left. This was worse in canter than trot, but similar on both reins. The horse hung on the right rein, so the bit has slid to the right. Lameness was only apparent on a long rein, when the head and neck posture was much straighter.*

side has previously been associated with pain in ridden horses (Dyson *et al.* 2017a), including hindlimb lameness, but the direction of the nose relative to the lame limb(s) was not investigated. In the current series, the nose consistently pointed in the opposite direction to the lame limb either on the lunge or when ridden and at its worst was also associated with tilting the neck. The tendency for the horse to 'hang' on one of the rider's hands was only observed in horses with a head tilt. Presumably, this posture is an attempt to ameliorate pain, as alteration in neck posture associated with neck pain has been described (Mayhew 2009). One horse showed head tilt and no lameness when ridden to a contact, but on a long rein, there was lameness and no head tilt. In addition, one horse developed a head tilt when lameness deteriorated with diagnostic analgesia. Head tilt was worse in canter than trot in two horses. In the trot, there are two cervical oscillations during each full stride, which are consistent among horses (Buchner *et al.* 1996; Clayton and Sha 2006). However, mediolateral movement of the head and neck varied among five 'sound' horses, with the centre of mass of the head and neck being held to the outside, the inside or across the circle line (Clayton and Sha 2006). In canter, the cranial part of the neck rotates down in midstance and rotates upwards during leading forelimb stance and the suspension phase (Denoix and Audigié 2001).

Seven horses (28%) showed alteration in lameness severity on a long rein vs. to a contact, presumably related to the position of the neck and head. This feature has previously been documented in horses with idiopathic hopping-type forelimb lameness when ridden (Dyson and Rasotto 2016). The mass of the head and neck represents approximately 10% of the body mass; because of the distance of the head and neck from the body's centre of gravity, the position of the head and neck has the potential to influence movement of the entire horse (Buchner *et al.* 1997). Head and neck position also affects ground reaction forces in the forelimbs (Weishaupt *et al.* 2006; Waldern *et al.* 2009). Alteration of the head and neck position may also influence the function of the muscles of the thoracic sling (m. rhomboideus cervicis, m. serratus ventralis cervicis) (Zsoldos and Licka 2015).

The root signature posture is considered indicative of compressive radiculopathy (McDonnell *et al.* 2010; Meij and Bergknut 2010; Henderson *et al.* 2015) and occurred sporadically in two horses. It was seen in four of eight horses with forelimb lameness associated with radiological abnormalities of the fourth to seventh cervical vertebrae (Ricardi and Dyson 1993), but has otherwise only rarely been documented in horses (Dyson 2003). However, it is a posture which was observed in one horse with a large cranial mediastinal mass (S. Dyson, unpublished data). In dogs, forelimb root signature posture is most commonly associated with cervical intervertebral disc extrusion–protrusion (de Lahunta *et al.* 2015). In one horse, in the current study, it was associated with local allodynia, which is also a feature of neuropathy in people (Landerholm 2010). Hyperaesthesia was seen in one other horse (Horse 14). Focal hyperaesthesia was reported in 48% of 91 horses with cervical vertebral compressive myelopathy (Levine *et al.* 2010); there was a significant association with periarticular osteophytes of the caudal cervical articular process joints identified at post-mortem examination. Hyperaesthesia is thought to be related to compression of dura, nerve root or dorsal horn lesions.

***Fig 3:** Horse 5, a 7-year-old dressage horse with a right forelimb lameness and episodic hopping-type lameness. At the start of work (a), no lameness was seen and the horse went freely forwards, on the bit, with the ears forwards. The horse rapidly developed lameness (b) and showed signs consistent with pain: above the bit, ears back, an intense stare, the nostrils flared and angular. The horse was reluctant to turn to the right. In (c), in trot, both forelimbs are off the ground simultaneously. There is advanced diagonal placement of the left hindlimb. The horse is above the bit and not taking a contact.*

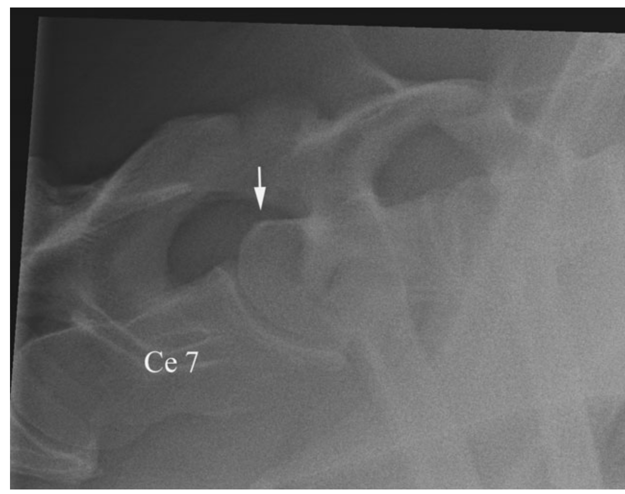

***Fig 4:** Lateral–lateral image of the seventh cervical (Ce 7) to second thoracic vertebrae of Horse 10, an 8-year-old general purpose riding horse who showed a hopping-type left forelimb lameness only on the lunge. When ridden, the horse hung on the left rein was reluctant to turn to the left and was strong and tense. There is subluxation of the seventh cervical and the first thoracic (T1) vertebrae, with dorsal displacement of the head of T1. There is a lack of congruity of the articular process joints between the seventh cervical and first thoracic vertebrae. Examination of the boiled-out bones post-mortem indicated an unusual range of motion of the joints with new bone formation on the dorsal aspect of T1 due to impingement of the caudal aspect of the articular processes of Ce 7 during extension. The surface area of the articular processes of T1 was larger than those of Ce 7. There was periarticular osteophyte formation on the ventral articular margins of the intercentral articular surface of Ce 7. The articular surfaces for the first rib articulations were modelled and asymmetrical.*

Exacerbation of lameness by diagnostic analgesia was observed in 76% of horses. This remarkable feature links horses in Groups 1, 2 and 3 and has been previously documented in association with idiopathic hopping-type forelimb lameness in ridden horses (Dyson and Rasotto 2016). It may be related to removal of afferent proprioceptive input, which can alter feedback loops used by the patient in moving (I. Mayhew, personal communication 2015).

Ultrasound-guided analgesia of caudal cervical articular process joints produced mild improvement in only two of six horses in which it was performed. If radiculopathy was a principle cause of pain, it seems unlikely that this would be influenced by intra-articular analgesia. However, it is possible that the use of up to 10 mL of mepivacaine may overdistend the joint capsule and result in lack of specificity. In a cadaver

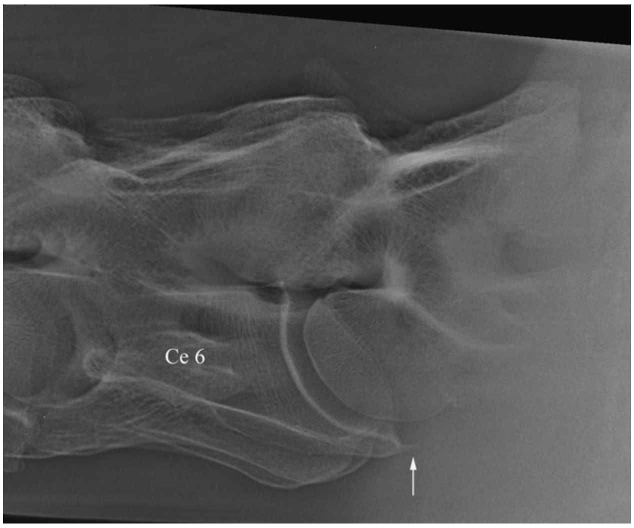

Fig 5: Lateral–lateral image of the sixth (Ce 6) and seventh cervical vertebrae of Horse 25, the same horse as in Fig 1. Cranial is to the left. There is moderate enlargement of the articular process joints between the sixth and seventh cervical vertebrae, with ventral buttressing and narrowing of the intervertebral foramen. No marked differences could be identified when comparing left to right and right to left ventrolateral-dorsolateral oblique images. There is also a spur on the caudoventral aspect of the vertebral body of the sixth cervical vertebra (arrow). Note the small spinous process on the craniodorsal aspect of the seventh cervical vertebra, a normal variant.

Fig 6: Lateral–lateral image of the fifth cervical to first thoracic vertebrae of Horse 15, the same horse as in Fig 2a. Cranial is to the left. The vertebrae have short pedicles and low slung articular process joints. The articular process joints of the sixth (Ce 6) and seventh cervical and seventh cervical and first thoracic vertebrae are moderately and massively enlarged, respectively, with ventral buttressing. This occludes the intervertebral foramen between the seventh cervical and first thoracic vertebrae. The vertebral canal of both the sixth and seventh cervical vertebrae is wedge-shaped. There is mild subluxation of the first thoracic vertebra (black arrowhead). Both ventral processes are transposed from the sixth to the seventh cervical vertebra (white arrows).

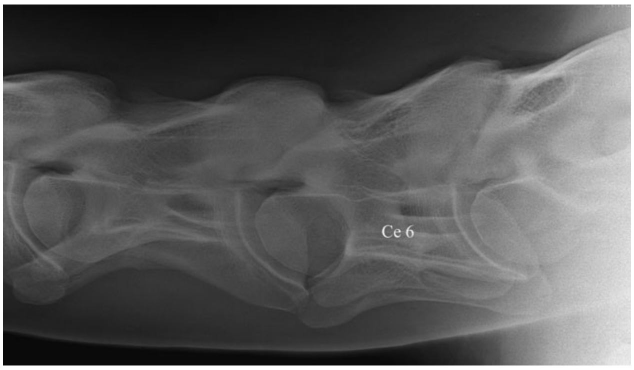

Fig 7: Lateral–lateral image of the fourth to seventh cervical vertebrae of Horse 23, a 5-year-old dressage horse, with a history of occasional 'neck locking', chronic neck stiffness and right forelimb lameness. Cranial is to the left. The vertebrae have short pedicles and low slung articular process joints. The articular process joints of the sixth (Ce 6) and seventh cervical are markedly enlarged with ventral buttressing; the articular process joints of the fifth and sixth cervical vertebrae are mildly enlarged. The vertebral canal of Ce 6 is wedge-shaped.

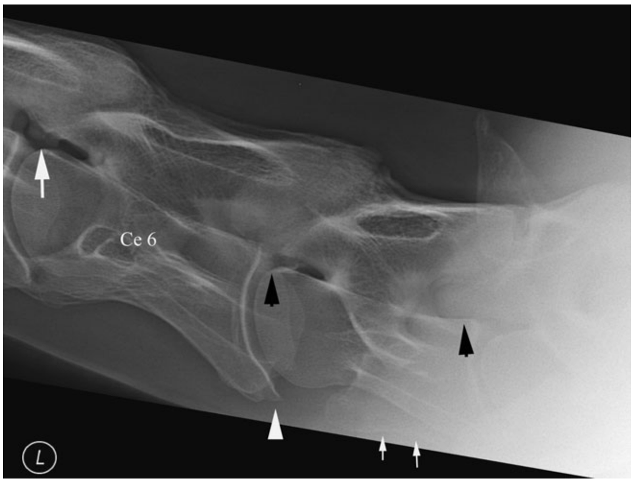

Fig 8: Lateral–lateral image of the fifth cervical to first thoracic vertebrae of Horse 13, an 8-year-old dressage horse, with left forelimb lameness only apparent in collected trot. Cranial is to the left. There are rounded spurs on the ventral aspect of the articular process joints of the fifth and sixth (Ce 6) cervical vertebrae (large white arrow). There is moderate enlargement of the articular process joints between Ce 6 and the seventh cervical (Ce 7) and Ce 7 and the first thoracic vertebrae, with ventral buttressing (black arrowheads) and narrowing of the intervertebral foramina. The shape of the articular process joints of the seventh cervical and first thoracic vertebrae is unusual. There is a spur on the caudoventral aspect of Ce 7 (white arrowhead). There is bilateral transposition of the ventral processes from Ce 6 to Ce 7 (small white arrows). The spinous process of T1 is angled cranially.

study of immature ponies (130 cm height at withers; estimated bodyweight 275–325 kg), the volume of the caudal cervical articular process joints was approximately 4 mL (Claridge *et al.* 2010).

Repeated forelimb stumbling was observed in one horse in Group 2 (worse after diagnostic analgesia of the hindlimbs) and three horses in Group 3 (16% overall). Horse 11 plaited the forelimbs at the walk and trot, which may have contributed to stumbling (**Supplementary Item 4**). During the period of the study, five additional horses were assessed which showed marked neck stiffness and a propensity to stumble, but no overt forelimb lameness (S. Dyson, unpublished data). All had severe osteoarthritis of the articular process joints between the sixth and seventh cervical vertebrae (n = 4), or between the seventh cervical and first thoracic vertebrae (n = 1, in association with fusion of the intercentral joint), with ventral buttressing and narrowing of the intervertebral foramina. Stumbling was also a prominent feature of three horses previously reported with idiopathic hopping-type forelimb lameness in ridden horses (Dyson and Rasotto 2016). Stumbling has also been associated with foot pain (Dyson and Ross 2011). Lower motor neuron dysfunction may possibly be involved in some horses in the current study; however, it is well recognised in people that gait stability is reduced in the face of musculoskeletal pain associated with a centrally mediated postural control deficit resulting in altered kinematics and kinetics (van den Hoorn *et al.* 2015).

Significant reduction in behaviour scores has been observed in lame horses after resolution of lameness using diagnostic analgesia (Dyson *et al.* 2018) indicating a causal relationship between ridden horse behaviour and pain. Application of the ridden horse behaviour ethogram and pain behaviour scores clearly demonstrated that the horses in this study were experiencing pain, with their scores being consistently higher than those reported for nonlame horses (maximum score of 6; median and mean score of 2 [$\pm$1.4]). (Dyson *et al.* 2017b). This substantiates previous observations of perceived pain in horses with idiopathic hopping-type forelimb lameness in ridden horses (Dyson and Rasotto 2016).

A high proportion of horses in the current study had severe (44%) or moderate (32%) modelling of the caudal cervical and cranial thoracic articular process joints consistent with osteoarthritis, occurring particularly at the articulations between the sixth and seventh cervical vertebrae or the seventh cervical and first thoracic vertebrae. However, in a gross post-mortem examination study of 53 horses in which the first cervical to seventh thoracic vertebrae were examined (Rombach 2013), lesions were most severe at the articulations between the third and fourth cervical vertebrae, followed by the articulations from the fifth cervical to first thoracic vertebrae, especially in horses $\geq$15 years of age. Periarticular osteophytes were most often present around the lateral joint margins of the articular processes; however, osseous proliferation frequently extended medially towards the intervertebral foramen with potential to compress the spinal nerves (Rombach 2013). Modelling of the caudal cervical articular process joints is a relatively common finding in mature horses (Down and Henson 2009; Dyson 2011a; K. Whitwell, personal communication) and is not necessarily associated with clinical signs. The severity of lesions is not necessarily well correlated with clinical signs (Kristoffersen *et al.* 2016), in part because associated soft tissue pathology may contribute to compressive radiculopathy. In dogs with cauda equina radiculopathy associated with lumbosacral stenosis, there is dynamic narrowing of the intervertebral foramen associated with hypertrophy of either the joint capsule of the articular process joints or the interarcuate ligaments, synovial cysts and periarticular osteophytes projecting into the intervertebral foramen (Meij and Bergknut 2010; Worth *et al.* 2017). Similar pathological changes have been documented in the caudal cervical region in horses (Dyson 2011a). Although computed tomography and computed tomographic myelography may give information not available from plain radiography (e.g. identification of fractures, intra-articular fragments and soft tissue proliferation), nerve roots cannot be assessed directly (Kristoffersen *et al.* 2016).

In a cadaver study of 'normal' ponies, maximal distension of the articular process joint capsules did not result in spinal cord or nerve root impingement, irrespective of neck position (Claridge *et al.* 2010). In an equine in vitro study, dimensions of the intervertebral foramina at the cervicothoracic junction decreased when the neck was extended compared with a neutral position or in flexion (Sleutjens *et al.* 2010). This could suggest that there may be greater occlusion of the intervertebral foramina by ventral periarticular osteophytes of the articular process joints in extension compared within a neutral position or flexion, enhancing the risk of compressive radiculopathy. However, the intervertebral foramina are not simple apertures, but complex three-dimensional tunnels, orientated from craniodorsomedial to caudoventrolateral. A recent study in dogs demonstrated that the intervertebral foraminal volume at the lumbosacral joint measured using computed tomography was influenced by flexion and extension (Worth *et al.* 2017). However, movement of the equine neck involves not only flexion and extension, but also lateral bending and axial rotation (Clayton and Townsend 1989), and the effects of these movements and associated muscle function are poorly understood in vivo. In a cadaver study, there was potential for narrowing of the dorsolateral or ventrolateral regions of the vertebral canal with neck movement (Schmidburg *et al.* 2012). The joint movements between the intervertebral joints are greatest in the caudal cervical region based on computer modelling (Zsoldos *et al.* 2010a,b). Lateral bending is also greater in the caudal and cranial cervical segments compared with the mid segment (Clayton *et al.* 2010, 2012). The head and neck segment functions as a cantilevered beam (Dyce *et al.* 1996), which creates large forces acting on and between the vertebral joints (Gellman and Bertram 2002), especially the caudal cervical vertebrae. The evidence of paraspinal nerve dysfunction in association with osteoarthritis of the caudal articular process joints has been suggested by measurement of motor unit action potentials (MUPs) in m. serratus cervicis (Wijnberg *et al.* 2009); nerve function assessed using MUPs was also influenced by head and neck position (Wijnberg *et al.* 2010).

In the current study, the frequency of transposition of the ventral processes of the sixth to the seventh cervical vertebra identified radiologically was low (12%), similar to the findings in a radiographic study of 270 horses (13%) (Santinelli *et al.* 2016) and a post-mortem study of 123 horses (19%) (May-Davis 2014), but lower than a radiographic study of 100 horses (24%) (DeRouen *et al.* 2016) and a computed tomography study of 78 horses (33%) (Veraa *et al.* 2016). It has been suggested that this vertebral anomaly may be associated with asymmetrical longus colli muscles which may predispose to development of secondary asymmetrical osteoarthritis of the articular process joints (May-Davis and Walker 2015).

In eight horses with osteoarthritis of the articular process joints between the seventh cervical and first thoracic vertebrae, these joints were markedly different in shape and orientation compared with the remaining horses and normal horses (Butler *et al.* 2017) (**Figs 6, 8**). The cervical vertebrae of several horses had short pedicles, low slung articular process joints and small intervertebral foramina. Nerve root compression at several sites was demonstrated in two of these horses at post-mortem examination. The role of bone or joint capsule pain is difficult to determine.

The caudal cervical and cranial thoracic nerve roots are intimately associated with the first ribs (Tagand and Barone 1964). Horse 10 had gross abnormalities of the articulations of both the left and right first ribs (left > right) with the first thoracic vertebra at post-mortem examination. Forelimb lameness associated with first rib abnormalities and nerve injury has previously been documented (Dyson 2011a).

Post-mortem findings verified the presence of nerve root injury in three of three horses. This is a diagnosis which is currently challenging to make in vivo. Electromyography has the potential to provide a presumptive diagnosis (Wijnberg *et al.* 2004, 2009), but results are influenced by head and neck position in symptomless horses (Wijnberg *et al.* 2010). Magnetic resonance imaging would be the potential imaging modality of choice to verify nerve root compression.

Limitations

It cannot be assumed that all horses had a common source of pain causing lameness. However, there were similar patterns of clinical features among horses. To report such patterns may encourage further detailed observations of horses, thereby advancing knowledge. Not all horses underwent scintigraphic assessment due to financial constraints and the high proportion of previously documented negative results in similar cases (Dyson and Rasotto 2016).

Conclusions

This study provides further evidence that caudal cervical or cranial thoracic radiculopathy can be associated with forelimb lameness.

Authors' declaration of interests

No conflict of interests have been declared.

Ethical animal research

The study was approved by the Clinical Ethical Review Committee of the Animal Health Trust.

Source of funding

None.

Acknowledgements

Emma Goodfellow for assistance with post-mortem examinations. Jennifer Stewart for histopathological assessments.

Manufacturers' addresses

[1]BCF Technology, Livingstone, UK.
[2]Nuclear Diagnostics, Gravesend, Kent, UK.
[3]GE Healthcare, Milwaukee, Wisconsin, USA.

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Supporting information

Additional Supporting Information may be found in the online version of this article at the publisher's website:

Supplementary Item 1: Summary of the ridden horse ethogram (from Dyson *et al.* 2017b).

Supplementary Item 2: Horse 6, a 5-year-old general purpose riding horse, which exhibited a hopping-type right forelimb lameness when ridden, has a head tilt with the nose to the left on the right rein on the lunge and holds the head to the left.

Supplementary Item 3: Horse 1, a 10-year-old general purpose riding horse, which exhibited a hopping-type left forelimb lameness when ridden.

Supplementary Item 4: Horse 11, a 12-year-old general purpose riding horse, which exhibited a hopping-type right forelimb lameness which was more obvious on the lunge, only on a soft surface, than when ridden.