Radiographic findings and anatomical variations of the caudal cervical area in horses with neck pain and ataxia: case–control study on 116 horses

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Abstract

Background Abnormalities of the ventral lamina of the sixth cervical vertebra (AVL-C6) are thought to exert abnormal stress on the articular process joints (APJs) of the cervicothoracic junction. The aim of the study was to investigate the association between AVL-C6 and radiographic findings in the caudal cervical area and between clinical signs of neck pain and ataxia and radiographic findings.

Methods Medical records of horses subjected to cervical radiography were reviewed. Horses were classified into those with neck pain (group C), those with ataxia (group A) and healthy horses (group H). Presence of AVL-C6 and increased size, dysplasia, remodelling, fragmentation and osteochondral fragment at the APJs (C5–T1) were recorded. Univariable logistic regression analysis was performed to identify the associations between explanatory and dependent variables. Variables with $P<0.2$ were included in the multivariable analysis.

Results One hundred and sixteen horses were included (44 in group C, 29 in group A, 66 in group H); 24 of 116 horses had radiographic AVL-C6. Age, AVL-C6 and overall/C6–C7 increase in size remained in the final models.

Conclusions The presence of AVL-C6 and moderate/severe increase in size of the caudal cervical APJs increase the odds of showing neck pain and, if severe, ataxia.

Introduction

The skeletal component of the neck is a site of lesions and pain in horses.[1] The indications for taking radiographs of the neck include signs of musculoskeletal pain, neurological signs and mechanical impairment of cervical spine mobility.[2–4] The most common radiographic abnormalities in the cervical area are cervical vertebral malformation/stenotic myelopathy, degenerative joint disease of the articular process joints (APJs) and osteochondrosis of APJs, which have been widely reported in the literature.[2 3 5 6] More recently, great attention has been paid to anatomical variations of the caudal cervical area, including the spinous processes of the seventh cervical vertebra (C7) and the first thoracic vertebra (T1), and transposition and/or abnormalities of the ventral lamina (also named the ventral tubercle or ventral process) of the sixth cervical vertebra (C6).[7–10] The prevalence of variations of the ventral tubercle of the transverse process of C6 varied from 13–24 per cent, to 18–19 per cent, to 33 per cent in radiographic, anatomical and CT studies, respectively.[7–10]

One of the functions of the ventral lamina of C6 is to provide an anchor point for the thoracic part of the longus colli muscle in the cervicothoracic junction, to stabilise, fixate, flex and rotate the vertebra.[11–13] It is believed that the thoracic portion of the longus colli muscle, with its strong reinforced tendon, helps to support the neck ventrally in the cervicothoracic junction.[12] Functional consequences of anatomical variations of the C6 transverse process are considered possible because abnormalities of the ventral lamina of C6 can interfere with the function of the longus colli muscle as it passes ventral to C7.[12–14] It has been demonstrated that the gross morphology of the longus colli muscle is variable in the presence of congenital

Veterinary Record (2020) doi: 10.1136/vr.105756

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Provenance and peer review Not commissioned; externally peer reviewed.

Received October 22, 2019
Revised August 15, 2020
Accepted September 4, 2020

variations of C6, or C6 and C7.[14] For this reason, the likelihood of biomechanical abnormalities leading to overuse injuries is extremely high.[14 15]

There are only limited data on the association of abnormal ventral lamina of C6 (AVL-C6) with radiographic abnormalities of the cervical vertebrae. However, a significant correlation has been found between AVL-C6 and clinical signs of cervical pain and/or C6 vertebral canal stenosis,[7 14] although other authors have failed to demonstrate correlation with clinical signs.[10 16] However, these studies included a wide range of clinical signs suggestive of neck pain, and radiographic findings were evaluated only for the presence or absence of osteoarthritis of the APJs or static vertebral canal stenosis.[7 10 14 16]

The aims of this study were (1) to investigate the association between the presence of AVL-C6 and radiographic abnormalities of the caudal cervical area (C5–T1) and (2) to assess the association between clinical signs of neck pain and spinal ataxia and several radiographic abnormalities using a group of control horses. The authors hypothesised (1) that horses with AVL-C6 have more frequent, and more severe, radiographic abnormalities of the caudal cervical area, and (2) that AVL-C6 is associated with clinical signs of cervical disease.

Materials and methods

Study population

The study design was an observational and retrospective analytical case–control study carried out according to the Strengthening the Reporting of Observational Studies in Epidemiology checklist.[17] The hospital database at the Veterinary Teaching Hospital (VTH) of the University of Perugia was searched for equine patients subjected to cervical radiography between January 2006 and October 2018. Medical records of horses were retrieved and available clinical data (breed, age, sex, discipline, history, reason for examination, clinical examination and final diagnosis) were recorded. The inclusion criteria were good radiographic quality (true laterality of the projections, appropriate exposure to evaluate the APJs and complete visualisation of the vertebrae) of the caudal cervical area (C5–C7), age more than one year and an available complete clinical examination.

Horses were classified into those with neck pain (group C), those with ataxia (group A) and healthy horses (group H). The clinical examination included neurological examination and orthopaedic examination as appropriate to assess the severity of clinical signs of the individual horses evaluated.

Horses were included in group C if they had a final diagnosis of neck pain as the cause of neck stiffness (inability/difficulties to eat from the ground and/or place the forelimb away from each other to eat from the ground) and/or neck fixing and/or forelimb lameness that resolved with intra-articular medication of the APJs; group A if horses showed clinical signs of 'spinal ataxia' (modified Mayhew grading system ≥1),[18] defined as inconsistent gait with alteration in the rate, range and force of movement,[18] in which ataxia was considered a consequence of cervical vertebra and/or cervicothoracic junction pathology; and group H (control group) if horses were referred for prepurchase examination, lameness or poor performance, and/or overall orthopaedic evaluation, in which complete clinical examination, including neurological and static and dynamic (walk on a straight line and a figure of eight, trot on a straight line and on circle on both hands on hard and soft ground) orthopaedic examination, ruled out the presence of cervical disease. In group H, radiographic examination of the neck was obtained because these horses were included in a previous study on radiographic changes in horses without cervical disease (lameness cases)[19] or as part of the radiographic protocol of the VTH for prepurchase examination and overall orthopaedic evaluation.

Horses were excluded if they had flaring of the caudal epiphysis of one or multiple vertebrae, if neck stiffness was related to the presence of abscesses of the neck musculature, or abnormalities of the cranial cervical area or strain of the neck muscles, and if other pathologies of the back were concomitant in horses with neck stiffness and the clinical signs were considered a consequence of a complex disease or to be secondary.

Radiography

Studies were performed with computed (CR) (2006–2016) or digital (DR) radiography (2017–2018), and a digital image analysis program (OsiriX; Pixmeo, Bernex, Switzerland) was used to evaluate the radiographs retrospectively, in a blinded fashion. The exposure factors varied depending on the size of the patient. Radiographic assessment was performed independently by two authors (including an expert in equine locomotor pathology and a PhD student in equine radiology). In cases of disagreement, the radiographs were viewed simultaneously by both authors and a consensus was reached.

For interpretation, all images were orientated cranial to the left and caudal to the right. The presence of the following findings was recorded: AVL-C6 (no vs yes); increased size of C5–C6 APJs (no, mild, moderate, severe), C6–C7 APJs (no, mild, moderate, severe) and C7–T1 APJs (no vs yes); size of C7–T1 APJs compared with C6–C7 APJs (smaller, same, bigger); dysplasia (no vs yes) of C5–C6, C6–C7 and C7–T1 APJs; remodelling (no vs yes) of C5–C6, C6–C7 and C7–T1 APJs; fragmentation (no vs yes) of C5–C6, C6–C7 and C7–T1 APJs; and osteochondral (OC) fragment (no vs yes) at C5–C6, C6–C7 and C7–T1 APJs.

C6 was considered normal if the two characteristic ventral laminae were seen arising from the transverse

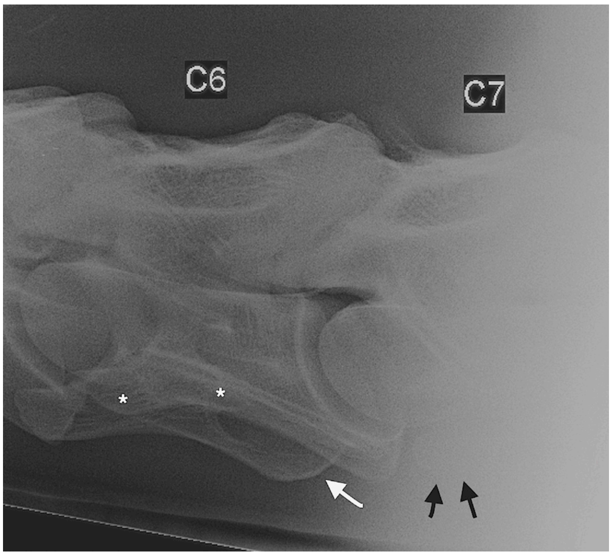

Figure 1 Lateral-lateral radiographic image of the sixth (C6) and seventh (C7) cervical vertebrae. There is unilateral absence of the ventral lamina of the transverse process of C6 (asterisks) which is transposed onto the ventral aspect of C7 (black arrows). There is also incomplete development of the ventral lamina of the transverse process of C6 on the side in which it is present (white arrow). Cranial is to the left.

processes and abnormal if it either presented an asymmetric appearance to the transverse processes or had unilateral or bilateral absence of the ventral lamina (figure 1). The increased size of C5–C6 and C6–C7 APJs was classified on the basis of the grading system proposed by Down and Henson[5] and grades pooled together in a lower number of classes considering the amount of periarticular new bone formation on the margins of the APJs to help in the statistical analysis (ie, avoid a disproportionate number of degree of freedom). Grade 1 was considered as no increase in size; grades 2, 3a and 4a as mild increase in size; grades 3b, 4b and 5a as moderate increase in size; and grade 5b as severe increase in size.[5] The C7–T1 APJ was considered to have increased in size only when there was radiographic evidence of bone sclerosis/lysis, periarticular new bone formation and irregularity of the outline of the APJ, on the basis of a preliminary study that identified the presence of normal variation in the size of the C7–T1 APJ compared with the C6–C7 APJ (smaller, same, bigger) (data not shown) (figure 2). Remodelling was defined as an irregular outline of the margin of the APJs.

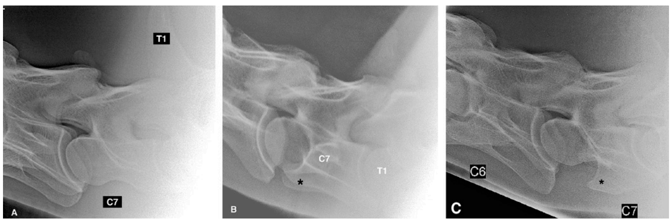

Figure 2 Lateral-lateral radiographic images of the sixth to seventh cervical (C6–C7) articular process joints and the seventh cervical to the first thoracic (C7–T1) articular process joints. Cranial is to the left. (a) The C7–T1 articular process joint is smaller than the C6–C7 articular process joint. (b) The C7–T1 articular process joint is bigger than the C6–C7 articular process joint; there is also bilateral transposition of the ventral lamina of C6 onto the ventral aspect of C7 (asterisk). (c) The C7–T1 articular process joint is approximately of the same size as of the C6–C7 articular process joint; there is also unilateral transposition of the ventral lamina of C6 onto the ventral aspect of C7 (asterisk).

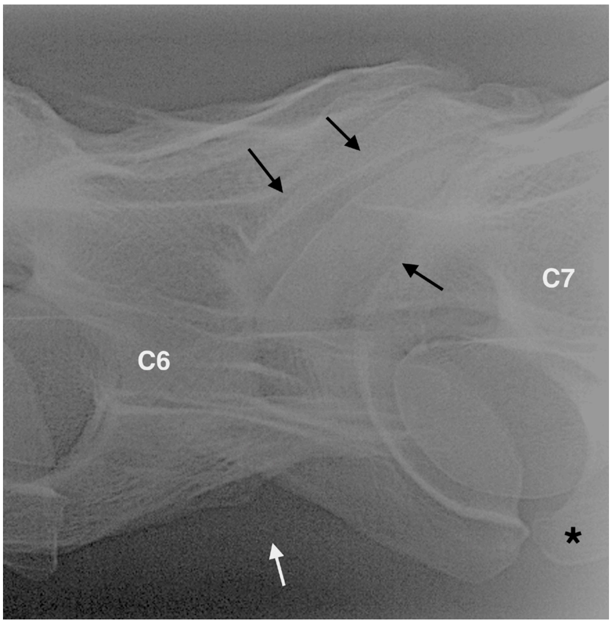

Figure 3 Lateral-lateral radiographic image of the sixth (C6) and seventh (C7) cervical vertebrae. There is asymmetry of the articular processes of the C6–C7 articular process joint, consistent with dysplasia (black arrows). There is also bilateral absence of the ventral laminae of the transverse processes of C6 (white arrow), which are transposed onto the ventral aspect of C7 (asterisk). Cranial is to the left.

Dysplasia was defined as widening of the joint space for asymmetric APJs (figure 3). Fragmentation (chronic fracture) of the APJ was considered present when an ill-defined, irregular, radiolucent line was detected crossing the APJs (figure 4).[3] Differently, an OC fragment was considered present when a single, rounded, well-defined OC fragment was detected (figure 5).

An overall evaluation was applied and included variables for each radiographic finding (increased size, remodelling, dysplasia, fragmentation, OC fragment), considering the higher score or the presence/absence in any APJs.

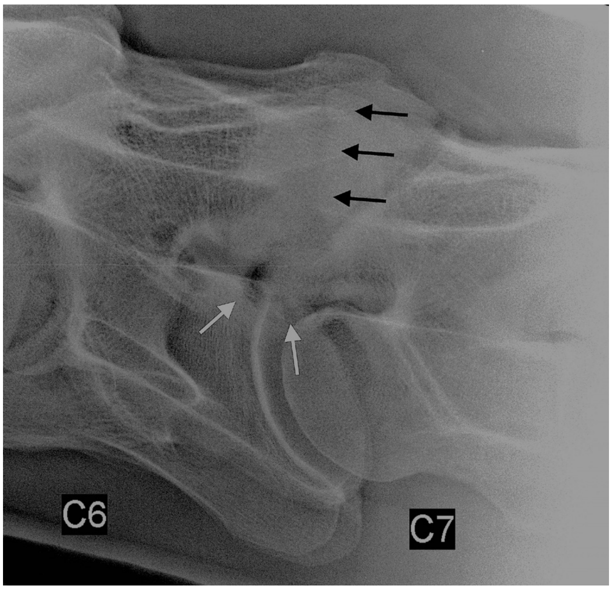

Figure 4 Lateral-lateral radiographic image of the sixth (C6) and seventh (C7) cervical vertebrae. There is an ill-defined vertical radiolucent line crossing the C6–C7 articular process joints (black arrows), consistent with fragmentation. The articular process joint of C6–C7 is severely enlarged with ventral buttressing (white arrows), which does not allow the identification of the caudal incisura of C6. Cranial is to the left.

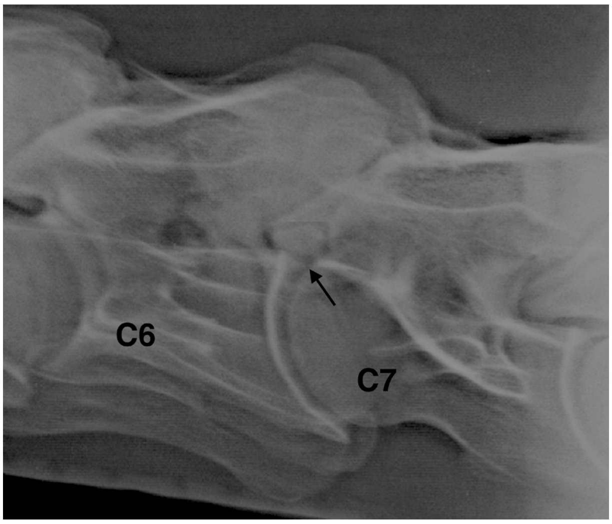

Figure 5 Lateral-lateral radiographic image of the sixth (C6) and seventh (C7) cervical vertebrae. There is a well-defined circular fragment at the ventral aspect of the C6–C7 articular process joints (black arrow). The articular process joint of C6–C7 is severely enlarged with ventral buttressing, which does not allow the identification of the intervertebral foramen. Cranial is to the left.

Statistical analysis

Statistical analyses were selected and performed by one of the authors (FB) using dedicated statistical software packages (R V.3.3.3 statistical software, The R Foundation for Statistical Computing; JASP V.0.11.1 computer software, JASP Team 2019). Each of the two clinical groups, group C and group A, was considered as the final outcome and analysed separately. For statistical analysis, entire males and gelding were pooled as male. Breed was divided into warmblood, thoroughbred, Arab and others. Discipline was divided into sports competition (show jumping, dressage, eventing), racing, endurance and others (pleasure, Western disciplines, showing, riding school and other).

Descriptive statistics were obtained for each group for the signalment data and each of the radiographic findings evaluated. In addition, descriptive statistics were obtained for the signalment data and each of the radiographic findings evaluated classified by the presence/absence of AVL-C6. Shapiro-Wilk's test to check for normality and Levene's test to check for homogeneity of variance were applied to continuous variables (age), and statistical tests were applied as appropriate.

The chi-squared test or Fisher's exact test was used, as appropriate, to assess differences between each clinical group (group C or group A) and group H with regard to signalment variables (sex, breed, discipline) and the evaluated radiographic findings. According to the normality of the distribution and equal or unequal variances, Student's *t* test or Mann-Whitney U test, as appropriate, was used to compare continuous variables (age).

The chi-squared test or Fisher's exact test was used, as appropriate, to assess differences between cases with and without AVL-C6 with regard to signalment variables (sex, breed, discipline) and the evaluated radiographic findings. According to the normality of the distribution and equal or unequal variances, Student's *t* test or Mann-Whitney U test, as appropriate, was used to compare continuous variables (age).

Phi coefficient (ϕ) or Cramer's V (ϕ_c) coefficient was calculated, as appropriate, for nominal variables (signalment and radiographic findings).

A univariable logistic regression model was developed to identify the associations between potential explanatory variables (signalment and radiographic findings) and each of the dependent variables (group C and group A). On the basis of phi (ϕ) or Cramer's V (ϕ_c) coefficients, nominal variables were considered highly correlated when the correlation coefficient was greater than 0.5 and statistically significant. To avoid collinearity in the models, a limited number of highly correlated variables were included in the models, based on those that were most useful from a clinical perspective and with a higher prevalence. As several radiographic parameters were highly correlated, two multivariable models were built for each outcome (group C and group A): one including signalment data, AVL-C6 and overall evaluation of the radiographic findings (model 1) and another including signalment data, AVL-C6 and radiographic findings for each APJ evaluated (model 2).

For each multivariable logistic regression model, variables with $P<0.2$ in the univariable analysis were considered for inclusion in the model; age was forced into each model. Variables were retained in the model by stepwise backward elimination of non-significant variables; variables were retained in the model if they significantly reduced the residual deviance of the model (likelihood ratio statistics). AUC, precision, sensitivity and specificity of the models were calculated. Significance was set at $P<0.05$.

Results

Study population

A total of 116 horses were included: 69 warmbloods, 16 thoroughbreds, 15 Arabs, seven Anglo-Arabs, three quarter horses, two Argentinian, two sport ponies, one Italian trotter and one paint horse. There were 58 geldings, 38 females and 20 entire males. Their age ranged from one year to 23 years (median 7 years; mean 7.5 years). The horses were used for a variety of disciplines: show jumping (68), racing (16), endurance (14), general purpose (10), dressage (4), showing (1), eventing (1), Western performance (1) and miscellaneous (1).

Of the 116 horses, 44 (37.9 per cent) were in group C and 29 (25 per cent) were in group A; 23 horses were included in both groups as they showed clinical signs of both neck pain and ataxia. Details on the reason for examination, history, duration of clinical signs before presentation and grade of ataxia (modified Mayhew grading system) of group C and group A are presented in online supplemental table 1. Of the 116 horses, 66

Table 1 Details on signalment, final diagnosis (group C and group A) and complaints on admission (group H) of the horses included in the study

Details	Group C (n=44)	Group A (n=29)		Group H (n=66)
Age (years)				
Mean±sd	7.7±4.7	6.1±4.8		7.8±4.6
Median	7	4*		7
Sex, n (%)				
Male	34 (77.2)	21 (72.4)		40 (60.6)
Female	10 (22.8)	8 (27.6)		26 (39.4)
Breed, n (%)				
Warmblood	27 (61.4)	12 (41.4)		40 (60.6)
Thoroughbred	6 (13.6)	9 (31)*		6 (9.1)
Arab	4 (9.1)	1 (3.5)		11 (16.6)
Other	7 (15.9)	7 (24.1)		9 (13.7)
Discipline, n (%)				
Sports competition	29 (65.9)	14 (48.3)		42 (63.6)
Racing	7 (15.9)	10 (34.5)*		5 (7.6)
Endurance	4 (9.1)	1 (3.5)		11 (16.7)
Other	4 (9.1)	4 (13.7)		8 (12.1)
Final diagnosis			Complaint, n (%)	
Malalignment	7†	12†	Prepurchase examination	5 (7.6)
Wedge-shaped vertebra	–	1	Overall orthopaedic evaluation	33 (50)
Arthropathy of the cervical APJ	38†	18†	Lameness or poor performance	28 (42.4)
Cervical diskospondylitis	2	2		
Cervical malformation	1	–		

*Significant difference (P<0.05) between the groups and the control.
†4 horses presented both malalignment and arthropathy of the cervical APJ.
APJ, articular process joint.

(56.9 per cent) were included in group H and were considered as controls.

Details on the breed, sex and age of the horses and the final diagnoses in each group are presented in table 1. There was a significant difference between group A and group H with regard to breed (P=0.008) and discipline (P=0.005). No significant differences between group C and group H were detected. In group A, there were more thoroughbred horses and horses used for racing than in group H.

In 31 horses (16 in group C, 12 in group A, 11 in group H), the radiographic study did not allow good evaluation of the C7–T1 APJs, and these horses were excluded from the evaluation of this area only.

Prevalence of AVL-C6

Out of the 116 horses, 24 (20.7 per cent) had radiographs showing AVL-C6. The details and radiographic findings evaluated for the presence/absence of AVL-C6 are summarised in online supplemental table 2 and online supplemental table 3. There was no significant difference between horses with and without AVL-C6 with regard to age, sex, discipline and breed, or in the radiographic findings evaluated, except for dysplasia of C6–C7 APJs. There was a significantly higher number of cases with dysplasia of C6–C7 APJs in horses with AVL-C6 compared with horses without (P=0.04).

Twelve horses in group A had malalignment of the cervical vertebra, of which five had angulation between C3 and C4, three at C6–C7, two at C7–T1 and one at C5–C6, with one horse presenting angulation in two sites (C3–C4 and C5–C6). Horses with AVL-C6 (6 of 12; 50 per cent) presented angulation between C7 and T1 (n=1), C6–C7 (n=1) and C5–C6 (n=1, and also C3–C4); in three horses, angulation was seen between C3 and C4. Seven horses in group C had malalignment of the cervical vertebra, of which two had angulation between C3 and C4, two at C6–C7, two at C7–T1 and one at C5–C6. Four of seven of these horses (57 per cent) showed AVL-C6: two had angulation between C3 and C4, one at C6–C7 and one at C7–T1. No horses in group H showed radiographic findings of malalignment.

Radiographic findings

Details on the radiographic findings in each group are presented in table 2.

There was a significant difference between group C and group H with regard to the presence of AVL-C6 (P=0.01), overall increased size of APJs (P<0.001) and at C5–C6 (P=0.01), C6–C7 (P<0.001) and C7–T1 (P<0.02), overall remodelling of APJs (P=0.007) and of C5–C6 (P=0.005), C6–C7 and C7–T1 APJs (P=0.002, P=0.001), presence of fragmentation overall (P=0.02) and at C6–C7 (P=0.002), and presence of OC fragments overall (P=0.04). A higher prevalence in group C was found for AVL-C6, for severely increased size, remodelling and fragmentation of the APJs, and for the presence of OC fragment(s) of APJs, compared with group H.

A significantly higher number of horses in group A were found with AVL-C6 (P=0.01), with overall severe

Table 2 Details on the radiographic findings detected in the study population classified by clinical signs of neck pain (group C) and ataxia (group A) and control horses (group H) and differences in the prevalence between groups

Radiographic findings	Group C (n=44; n=28*)	Group A (n=29; n=17*)	Group H (n=66; n=55*)	Radiographic findings	Group C (n=44; n=28*)	Group A (n=29; n=17*)	Group H (n=66; n=55*)
AVL-C6, n (%)				C6–C7 increase in size, n (%)			
Yes	14 (31.8)†	10 (34.5)†	8 (12.1)	Mild	4 (9.1)†	6 (20.7)	16 (24.2)
				Moderate	12 (27.3)	5 (17.2)	15 (22.7)
				Severe	18 (40.9)†	8 (27.6)	8 (12.1)
Overall increase in size, n (%)				C6–C7 remodelling, n (%)			
Mild	5 (11.4)	6 (20.7)	16 (24.2)	Yes	32 (72.7)†	18 (62.1)	35 (53)
Moderate	13 (29.5)	5 (17.2)	16 (24.2)				
Severe	18 (40.9)†	8 (27.6)†	7 (10.6)				
Overall remodelling, n (%)				C6–C7 dysplasia, n (%)			
Yes	36 (81.8)†	20 (68.9)	37 (56.1)	Yes	5 (11.4)	3 (10.3)	2 (3)
Overall dysplasia, n (%)				C6–C7 fragmentation, n (%)			
Yes	6 (13.6)	3 (10.3)	4 (6.1)	Yes	7 (15.9)†	4 (13.8)†	0 (0)
Overall fragmentation, n (%)				C6–C7 OC fragment, n (%)			
Yes	7 (15.9)†	4 (13.8)†	0 (0)	Yes	0 (0)	1 (3.4)	0 (0)
Overall OC fragment, n (%)				C7–T1 increase in size, n (%)			
Yes	5 (11.4)†	2 (6.9)†	0 (0)	Yes	8 (28.6)†	3 (17.6)	4 (7.3)
C5–C6 increase in size, n (%)				C7–T1 remodelling, n (%)			
Mild	7 (15.9)	3 (10.3)	7 (10.6)	Yes	7 (25)†	3 (17.6)	5 (9.1)
Moderate	10 (22.7)†	7 (24.1)†	5 (7.6)				
Severe	2 (4.5)†	1 (3.4)	0 (0)				
C5–C6 remodelling, n (%)				C7–T1 dysplasia, n (%)			
Yes	19 (43.2)†	11 (37.9)†	12 (18.2)	Yes	3 (10.7)	1 (5.9)	2 (3.6)
C5–C6 dysplasia, n (%)				C7–T1 fragmentation, n (%)			
Yes	0 (0)	0 (0)	1 (1.5)	Yes	1 (3.6)	0 (0)	0 (0)
C5–C6 fragmentation, n (%)				C7–T1 OC fragment, n (%)			
Yes	0 (0)	0 (0)	0 (0)	Yes	1 (3.6)	0 (0)	0 (0)
C5–C6 OC fragment, n (%)				C7–T1 size, n (%)			
Yes	1 (2.3)	1 (3.4)	2 (3)	Smaller	13 (46.4)	11 (64.7)	37 (67.3)
				Same	11 (39.3)	4 (23.5)	14 (25.5)
				Bigger	4 (14.3)	2 (11.8)	4 (7.3)

*Number of horses in which evaluation of the C7–T1 articular process joint was performed.
†Significant difference (P<0.05) between the group and the control (chi-squared or Fisher's exact test).
AVL-C6, abnormal ventral lamina C6; OC, osteochondral.

increase in size (P=0.01) and with moderate increase in size at C5–C6 APJs (P=0.04), with overall (P=0.02) and at C6–C7 (P=0.007) fragmentation and with overall OC fragment (P=0.03) of APJs, and with remodelling of C5–C6 APJs (P=0.01), when compared with group H.

Correlations between variables

There was a high correlation between breed and discipline (ϕ_c=0.77). No high correlations were identified between signalment data (sex, breed and discipline) and radiographic findings, and neither between AVL-C6 and radiographic data.

Significant correlations between radiographic parameters of APJs are summarised in online supplemental table 4.

Breed was chosen to be included in model 1 and model 2, instead of discipline.

Overall increase in size was chosen to be included in model 1, instead of overall remodelling, as it is considered more clinically relevant and more objective to be classified on radiographic images.

Increase in size of C5–C6 and C6–C7 APJs and dysplasia of C6–C7 APJs were chosen to be included in model 2, instead of C5–C6 remodelling and C7–T1 increase in size, as these are considered more objective to be classified on radiographic images.

Univariable analyses

The results of the univariable analyses are presented in online supplemental table 5.

Multivariable analyses

The results of the multivariable analyses are presented in table 3.

In both group C and group A, age, AVL-C6 and overall increase in size of APJs remained in the final model 1. In model 2, the same parameters remained in the final model, with the overall increase in size replaced by increase in size at C6–C7 APJs.

Horses with AVL-C6 had 4.7 and 8.2 times greater odds of showing neck pain and ataxia, respectively. There were lower odds of showing neck pain (odds ratio

Table 3 Details on the parameters that remained in the final multivariable logistic regression analyses performed in horses with neck pain (group C) and spinal ataxia (group A)

	Group C			Group A		
	Model 1			Model 1		
Variables	OR	95% CI	P value	OR	95% CI	P value
Age (years)	0.87	0.78 to 0.98	0.03*	0.73	0.59 to 0.91	0.005*
AVL-C6						
No	Ref	1		Ref	1	
Yes	4.73	1.54 to 14.51	0.0007*	8.2	2.01 to 33.37	0.003*
Overall increase in size						
No	Ref	1		Ref	1	
Mild	1.01	0.25 to 4.08	0.98	1.23	0.50 to 11.64	0.26
Moderate	4.42	1.33 to 14.64	0.01*	0.61	0.37 to 9.95	0.43
Severe	18.66	4.37 to 79.58	<0.001*	13.09	8.81 to 151.13	<0.001*
AUC	0.79			0.87		
Sensitivity	0.57			0.72		
Specificity	0.8			0.89		
McFadden R^2†	0.21			0.34		
	Group C			Group A		
	Model 2			Model 2		
Age (years)	0.88	0.79 to 0.99	0.04*	0.76	0.62 to 0.93	0.009*
AVL-C6						
No	Ref	1		Ref	1	
Yes	5.13	1.67 to 15.78	0.004*	8.19	2.05 to 22.71	0.03*
Increase in size of C6–C7						
No	Ref	1		Ref	1	
Mild	0.66	0.16 to 2.79	0.58	2.34	0.49 to 11.01	0.28
Moderate	3.68	1.14 to 11.91	0.03*	1.99	0.39 to 10.16	0.4
Severe	12.31	3.23 to 46.78	<0.001*	18.12	6.33 to 32.65	<0.001*
AUC	0.78			0.86		
Sensitivity	0.55			0.72		
Specificity	0.78			0.9		
McFadden R^2†	0.19			0.32		

Model 1 includes signalment data, AVL-C6 and overall evaluation of radiographic findings.
Model 2 includes signalment data, AVL-C6 and radiographic findings of each articular process joint evaluated.
*Significant difference (P<0.05).
†A range from 0.2 to 0.4 indicates a good model fit.
AVL-C6, abnormal ventral lamina C6; CI, confidence interval; OR, odds ratio; ref, reference.

(OR) 0.87) and ataxia (OR 0.73) with increasing age. Horses with moderate (OR 4.4) and severe (OR 18.6) increase in size of APJs have higher odds of showing neck pain. In addition, horses with severe increase in size of APJs had 13.9 higher odds of showing spinal ataxia.

Discussion

In partial agreement with the initial hypotheses, the results demonstrated that there are significant differences in the prevalence of radiographic abnormalities of the caudal cervical area between horses with clinical signs of neck pain and ataxia and horses without them. In contrast to the initial hypotheses, no differences were found in radiographic changes of the caudal cervical APJs between horses presenting with AVL-C6 and horses with the classical shape of the ventral lamina of C6.

The overall prevalence of radiographic variations of the ventral lamina of C6 in this study was 20.7 per cent, which is similar to that of previous studies which detected a prevalence of 13.3–24 per cent using the radiographic technique[7 9 16] and 18.3–19.8 per cent using anatomical dissection,[8 14 20] but lower than of other studies which used CT (33.3 per cent)[10] or radiography (38 per cent).[16] The lower prevalence detected in this radiographic study compared with the CT study[10] is probably related to the higher sensitivity and multiplanar reconstruction of the advanced diagnostic technique compared with plain radiography. The shape of the transverse process of the cervical vertebrae up to C6 can be evaluated using oblique lateral views of the caudal cervical area,[21] which also allow differentiation of the left from the right side. Complete assessment of the whole C7 is not always possible in all horses. However, the use of oblique projections would probably have allowed an additional evaluation of the transverse processes of the caudal cervical area. A higher prevalence was obtained in a recent radiographic study in a subgroup of included horses, and the authors hypothesised selection bias is possible.[16]

Some studies demonstrated a predisposition of thoroughbreds, Dutch warmbloods and females to variations in the ventral lamina of C6.[8 9 16] However, in agreement with other studies,[7] no significant differences in breed and sex were detected between horses with and without AVL-C6.

It has been suggested that the deviation in the attachment of the thoracic part of the longus colli muscle as a consequence of AVL-C6 can result in dysfunction and therefore instability of the cervicothoracic junction.[14] In addition, it was speculated that, in horses with abnormalities in the attachment of the longus colli muscle, the C6–C7 and C7–T1 APJs are predisposed to developing arthropathy because these articulations are highly mobile, can undergo higher stresses and the biomechanical abnormalities can lead to overuse injuries.[14 15] However, in agreement with a previous study which considered osteoarthritis of the APJs,[7 16] in the present study there were no differences in the prevalence of the evaluated radiographic changes (increased size, remodelling, fragmentation (chronic fracture) and OC fragments) between horses with and without AVL-C6. The result supports the findings obtained by DeRouen *et al*[7] and suggests that the presence of AVL-C6 does not predispose to the development of more severe radiographic changes of the APJs of the caudal cervical area and cervicothoracic junction and/or the presence of OC fragments, contrary to the initial hypothesis. It is possible that different genetic (for OC fragments) and/or acquired factors (for radiographic findings of degenerative joint disease) act independently from those responsible for AVL-C6.

In one study, asymmetry of the diarthrodial articulations, considered as dysplasia in the radiographic study, was noted at C6 and C7 in horses with AVL-C6.[14] In the present study, C6–C7 APJ dysplasia was significantly higher in horses presenting with AVL-C6 compared with horses without.

However, AVL-C6 and moderate/severe increase in size of the caudal APJs, especially at C6–C7, significantly increased the odds of showing neck pain in all final multivariable models. This result is of particular interest and leads to consideration of the specific clinical signs evaluated.

Previous studies have evaluated the association between the presence of AVL-C6 and clinical signs of cervical pain, including horses with cervical disease as a single group of 'horses with clinical signs' and a control group of horses without complete clinical examination.[7–10] Recently another study investigated spinal ataxia, cervical pain at palpation, presumed brachial plexus neurological lameness and horses with at least one of several clinical signs of neck pain, and included a control group of horses with complete clinical examination.[16 22] Conflicting results were obtained, with some authors finding a correlation[7] and others not.[10 16] Comparison between these different studies and also between them and the present study is difficult as the criteria to include horses in groups with clinical signs differ, as well as the criteria of the radiographic findings evaluated. In this study, the authors chose to investigate two different clinical signs (group C and group A) related to the cervical area separately and to use a control group of horses in which complete examination was performed to rule out the presence of cervical disease as part of a previous study. In agreement with DeRouen *et al*,[7] horses with AVL-C6 had 4.73 greater odds of showing neck pain, characterised here as clinical signs of inability to eat from the ground and/or straddling the forelimbs excessively and/or neck fixing and/or forelimb lameness that resolved after medication of the APJs. In addition, horses presenting moderate and severe increase in size of the APJs had 3.68–4.42 and 12.31–18.66 times higher odds of showing neck pain. Considering that there were no differences in the severity of radiographic abnormalities related to osteoarthritis of the APJs in horses with and without AVL-C6, it is possible that different mechanisms act simultaneously for these clinical signs. DeRouen *et al*[7] speculated that alteration in the attachment of muscles due to abnormal C6 may result in perceived pain or reduced range of motion. It has been demonstrated that, in the presence of congenital variations of C6 and/or C7, gross morphology of the longus colli muscle is variable, showing asymmetry of the bundles and layers, and hypertrophy.[14] The longus colli muscle is a proprioceptive muscle with rich proprioceptive innervation,[23] and asymmetries develop in equine muscles that are used incorrectly or improperly innervated.[24] The cause of neck pain may be related to the postural and locomotive dysfunction due to the influence of muscle tonicity on neural pathways in horses with AVL-C6.[14] For these reasons, it is possible that horses with AVL-C6 and moderate/severe changes of the APJs are less tolerant to advanced osteoarticular changes, resulting in the development of clinical signs reported here. This is in contrast to a recent study which reported AVL-C6 is not associated with clinical signs in warmblood horses. However, only the absence/presence of degenerative changes of the APJs was investigated, not the severity of changes, as done in the present study.[16]

In addition, it has been demonstrated that, in some horses presenting with congenital variation of C6 and C7, it is possible to identify congenital malformation of the first rib, for example hypoplasia or bifid development.[17] A thoracic inlet syndrome, as described in people, cannot be excluded as a cause of neck pain, especially in horses showing forelimb lameness related to the cervical spine.[20–25]

In this study, 40.9 per cent of horses with neck pain presented overall and C6–C7 severe increase in size compared with 10.6–12.1 per cent in the control group. The result is in contrast to the previous study, used here to classified the degree of increase in size, that failed to demonstrate association between grades of caudal APJs enlargement and clinical signs.[5] However, for the purpose of the present study, the seven grades of enlargements of APJs[5] were pooled in three classes of severity on the basis of the amount of periarticular new bone formation onto the APJs. This could have affected the results.

Horses with AVL-C6 had 8.2 times higher odds of showing clinical signs of spinal ataxia. Spinal ataxia is a clinical sign characterised by inconsistent gait, with alterations in the rate, range and force of movement. It is the result of the compression of the spinal cord inside the vertebral canal.[18 26–28] Compression of the spinal cord can be related to cervical vertebral stenotic myelopathy of the cervical vertebra, which is well described in the literature and named 'Wobbler Syndrome', as well as increased size of the APJs, which can induce compression of the spinal cord. Ataxia as a consequence of arthropathy of the APJs is less common than of cervical vertebra stenosis.[22 28] In the present study group, malalignment (12 horses) and static stenosis (one horse with wedge-shaped vertebra) of the cervical vertebra were detected in 13 horses, using the criteria reported in the literature,[3] at different locations, and approximately 50 per cent of these cases showed AVL-C6. As previously reported, instability of the cervicothoracic junction can be a consequence of aberrant attachment of the longus colli muscle.[14] The thoracic portion of the longus colli muscle, with its reinforced tendon, helps to support the cervicothoracic junction ventrally,[12] especially because the horse lacks a ventral longitudinal ligament until the eighth thoracic vertebra.[23] Whether instability of the caudal cervical vertebrae has consequences for the middle cervical area should be investigated. However, simultaneous genetic abnormalities in the development of the middle and caudal areas cannot be excluded because dysplasia of the vertebral head and/or elongation of the vertebral arch are often the cause of cervical vertebral stenotic myelopathy of the middle cervical area.[3] In addition, it has also been demonstrated that horses with AVL-C6 had an intravertebral sagittal ratio less than 0.5 at the C6 site, suggesting that AVL-C6 may be associated with other simultaneous regional developmental abnormalities, including the formation of a narrow vertebral canal.[7] Unfortunately, the intravertebral sagittal ratio at the C6 site was not investigated in the present study.

The presence of overall and C6–C7 APJ severe increase in size remained in the final model for spinal ataxia (OR 13.09–18.12). This is logical as the greater the increase in size of the APJs, the higher the probability that it results in spinal cord compression and development of clinical signs of ataxia.

Age also remained in the final models of group C and group A, with older horses having a lower risk of presenting neck pain and ataxia. Correlation between age and increase in size of the APJs was not demonstrated,[4] and it is possible that factors other than age (ie, length of the neck, weight of the horse) have an effect on the development of some radiographic changes and clinical signs. In the present study's population, it is possible that horses presenting with predisposing factors (ie, AVL-C6, moderate/severe increase in size of APJs), as demonstrated, for neck fixing, inability to eat from the ground or forelimb lameness or neck origin might develop clinical signs earlier.

In addition, 23 out of 44 (~50 per cent) included horses showed both clinical signs of ataxia and neck pain. It is possible that horses showing spinal ataxia can be referred for further investigation earlier than horses that have no neurological signs, influencing the results in group C.

Finally, it was interesting to note that some radiographic abnormalities of the caudal cervical area were commonly identified in horses without detectable clinical signs of cervical disease, supporting previous studies that identified new bone formation of the caudal cervical APJs as a common finding.[4 29] In accordance with a previous study,[5] remodelling and increased size of the caudal cervical APJs were commonly detected in healthy horses, but were of mild/moderate severity. The prevalence of severely increased size of the caudal APJs was significantly higher in horses with neck pain or ataxia (40.9 per cent and 26.7 per cent) and uncommon in healthy horses (10.6 per cent). Remodelling had a high prevalence in healthy horses (56.1 per cent), especially at C6–C7 (53 per cent), but significantly lower than that of horses with neck pain (72.7 per cent).

Some radiographic findings such as fragmentation and OC fragments were not detected in this group of control horses and significantly differ from prevalence in horses with neck pain (15.9 per cent, 11.4 per cent). Again, oblique radiographic projections of the caudal cervical area were not reviewed for the purpose of this study because they are not routinely acquired in all horses. To avoid bias, the authors decided to evaluate only radiographic projections that were available for all horses. As a consequence, it is possible that some lesions had been missed on standard lateral radiographic views because oblique projections allow good evaluation of the single APJ.[21]

There were several limitations to the study, including its retrospective design. Some signalment data that can influence or have an effect on the development of changes in the caudal APJs, such as weight of the horse, length of the neck or conformation of the neck, could not be obtained retrospectively from the medical records. Some radiographic abnormalities had a low prevalence, for example fragmentation, dysplasia or the presence of an OC fragment, which may have influenced the results of the multivariable models. In some horses, the evaluation of C7–T1 was not possible because the exposure and brightness of the APJs were suboptimal. To avoid bias in interpretation of the C7–T1 APJs, the authors decided to exclude some cases for the evaluation of this area. It was demonstrated in a postmortem study that radiographic changes at C7–T1 APJs are common, even if clinical significance has to be established.[30] However, in the present study, increase in size and remodelling at C7–T1 had a significantly higher prevalence in horses with clinical signs of neck pain compared with control horses. In the authors' opinion, as model 1 was built considering the overall changes detected, the exclusion of some horses from C7–T1 evaluation had marginally affected the results of the study.

Some possible causes of neck pain, for example congenital malformation of the first rib, were impossible to assess in this retrospective study because evaluation of the first rib generally requires a specific radiographic projection, and evaluation of this area in standing weight bearing lateral view of the caudal neck is not always easy.

Finally, the controls were horses in which complete clinical examination was performed to rule out the presence of neck pain and/or ataxia. However, it is not possible to establish whether the cervical abnormalities detected in horses considered to be healthy are responsible for more subtle clinical signs, such as poor performance or mild discomfort in specific situations (ridden and/or performing specific sport exercises), especially when considering the clinical sign of cervical pain, because data on the role of cervical pathology in horses showing poor performance are scant.

In conclusion, the results show how anatomical variation of the ventral lamina of the transverse process of C6 increases the odds of the development of clinical signs of cervical disease, such as neck pain and ataxia, in association with moderate/severe increase in size of the caudal APJs. As a consequence, the authors consider it appropriate to obtain radiographs of the cervical spine of sufficient quality to allow a careful morphological evaluation of C6. Mild increases in size and remodelling of the caudal cervical APJs should not be overestimated because they are commonly detected in horses without clinical signs of cervical disease. However, radiographic findings of moderate and severe increase in size may be more important for neck pain and ataxia. Finally, dysplasia, fragmentation and the presence of an OC fragment of the APJs may be investigated in a higher number of horses because these may have more clinical significance.

Contributors FB and IS contributed to study design, study execution, data analysis and interpretation, and preparation of the manuscript. ADM contributed to study design and preparation of the manuscript. RG, MP and JMR contributed to study design, data interpretation and preparation of the manuscript. All authors gave their final approval of the manuscript.

Funding The authors have not declared a specific grant for this research from any funding agency in the public, commercial or not-for-profit sectors.

Competing interests None declared.

Ethics approval This study was performed in accordance with the guidelines of the Animal Care and Local Ethics Committee of the University of Perugia.

Data availability statement No data are available.

► Additional material is published online only. To view please visit the journal online (http://dx.doi.org/10.1136/vetrec-2019-105756).

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Supplementary table 1. Details of reason for examination, history, duration of clinical signs before presentation and grade of ataxia (modified Mayhew's grading system) of *group C* and *group A.*

	Group *C* (n= 44)	**Group *A* (n = 29)**
Reason for examination by the referring vet		
Ataxia	11	17
Forelimb lameness	10	5
Neck stiffness	18	4
Chronic weight loss	2	2
Neck pain	3	1
History from the owner/rider		
Episode/s of neck fixing with/without history of stumbling/lameness	18	9
Abnormal gait	-	6
Inability/difficulties to eat from the ground	6	6
Forelimb placed away each other to eat from the ground	6	4
+ restricted flexibility during work under the saddle	2	-
+ forelimb lameness during work under the saddle	5	-
Forelimb lameness	5	4
Duration clinical signs before admission (gg)		
Median	25	20
Range	1-365	1-365
Ataxia grade (Mayhew's modified grading system)*		
Median	1	2
Range	1-3	1-4

* Mayhew's modified grading system: Grade 0: Normal; Grade 1: Subtle deficits only visible under special circumstances and not always consistent; Grade 2: Mild deficits but visible at all gaits and tests including walking in straight line; Grade 3: Moderate deficits visible to any untrained eye; Grade 4: Severe deficits with risk of falling easily even if just standing; Grade 5: Recumbent unable to stand.

Supplementary table 2. Details of signalment of the horses included in the study classified by presence/absence of abnormal ventral lamina of C6 (AVL-C6).

Details	Horses with AVL-C6 (n=24)	Horses without AVL-C6 (n=92)	p-value
Age (years)			0.96
Mean ± S.D.	7.5 ± 4.9	7.5 ± 4.5	
Median (range)	7 (1-20)	7 (1-23)	
Sex			0.36
Male	18 (75%)	60 (65.2%)	
Female	6 (25%)	32 (34.8%)	
Breed			0.78
Warmblood	15 (62.5%)	54 (58.7%)	
Thoroughbred	3 (12.5%)	13 (14.1%)	
Arab	4 (16.7%)	11 (11.9%)	
Other	2 (8.3%)	14 (15.3%)	
Discipline			0.97
Sport Competition	16 (66.7%)	57 (61.9%)	
Racing	3 (12.5%)	13 (14.1%)	
Endurance	3 (12.5%)	12 (13.1%)	
Other	2 (8.3%)	10 (10.9%)	

AVL-C6 = abnormal ventral lamina C6
S.D. = standard deviation

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Supplementary table 3. Details of the detected radiographic findings classified by presence/absence of abnormal ventral lamina of C6 (AVL-C6).

Details	Horses with AVL-C6 (n=24; n=19§)	Horses without AVL-C6 (n=92; n=66§)	p-value
Overall increase size			0.66
No	8 (33.3%)	30 (32.5%)	
Mild	6 (25%)	17 (18.4%)	
Moderate	4 (16.6%)	26 (28.6%)	
Severe	6 (25%)	19 (20.5%)	
Overall remodeling			0.89
No	8 (33.3%)	32 (34.8%)	
Yes	16 (66.7%)	60 (65.2%)	
Overall dysplasia			0.11
No	20 (83.3%)	86 (93.5%)	
Yes	4 (16.7%)	6 (6.5%)	
Overall fragmentation			0.16
No	24 (100%)	85 (92.4%)	
Yes	0 (0%)	7 (7.6%)	
Overall OC fragment			0.96
No	24 (100%)	85 (92.4%)	
Yes	0 (%)	7 (7.6%)	
C5-C6 increase size			0.47
No	17 (70.8%)	67 (72.8%)	
Mild	2 (8.4%)	13 (14.2%)	
Moderate	5 (20.8%)	10 (10.8%)	
Severe	0 (0%)	2 (2.2%)	
C5-C6 remodeling			0.84
No	17 (70.8%)	67 (72.8%)	
Yes	7 (29.2%)	25 (27.2%)	
C5-C6 dysplasia			0.60
No	24 (100%)	91 (98.9%)	
Yes	0 (0%)	1 (1.1%)	
C5-C6 fragmentation			1
No	24 (100%)	92 (100%)	
Yes	0 (0%)	0 (0%)	
C5-C6 OC fragment			0.60
No	24 (100%)	91 (98.9%)	
Yes	0 (0%)	1 (1.1%)	
C6-C7 increase size			0.51
No	10 (41.7%)	30 (32.6%)	
Mild	5 (20.8%)	17 (18.5%)	
Moderate	3 (12.5%)	25 (27.2%)	
Severe	6 (25%)	20 (21.7%)	
C6-C7 remodeling			0.82
No	10 (41.7%)	36 (39.1%)	
Yes	14 (58.3%)	56 (60.9%)	
C6-C7 dysplasia			**0.04**
No	**20 (83.3%)**	**89 (96.7%)**	
Yes	**4 (16.7%)**	**3 (3.3%)**	
C6-C7 fragmentation			0.16
No	24 (100%)	85 (92.4%)	
Yes	0 (%)	7 (7.6%)	
C6-C7 OC fragment			0.58
No	23 (95.8%)	90 (97.8%)	
Yes	1 (4.2%)	2 (2.2%)	
C7-T1 increase size			0.08
No	14 (73.7%)	59 (89.4%)	
Yes	5 (26.3%)	7 (10.6%)	
C7-T1 remodeling			0.32
No	15 (78.9%)	58 (87.8%)	
Yes	4 (21.1%)	8 (12.2%)	

C7-T1 dysplasia			0.21
No	19 (100%)	61 (92.4%)	
Yes	0 (0%)	5 (7.6%)	
C7-T1 fragmentation			0.58
No	19 (100%)	65 (98.5%)	
Yes	0 (0%)	1 (1.5%)	
C7-T1 OC fragment			0.58
No	19 (100%)	65 (98.5%)	
Yes	0 (0%)	1 (1.5%)	
C7-T1 size			0.20
Smaller	9 (47.4%)	42 (63.6%)	
Same	6 (31.5%)	19 (28.8%)	
Bigger	4 (21.1%)	5 (7.6%)	

AVL-C6 = abnormal ventral lamina C6
§ number of horses in which evaluation of C7-T1 articular process joint was performed

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Supplementary table 4. Details of the significant correlations coefficient, phi and Cramer's V, between the radiographic findings evaluated in this study.

Radiographic findings	Overall remodelling	C5-C6 remodeling	C6-C7 increase size	C6-C7 remodeling	C6-C7 dysplasia	C6-C7 OC fragment	C7-T1 increase size	C7-T1 remodeling	C7-T1 dysplasia	C7-T1 fragmentation	C7-T1 OC fragment	C7-T1 size
Overall increase size	0.92[b]	0.59[b]	0.96[b]	0.82[b]								
Overall remodelling			0.92[a]	0.85[a]								
Overall dysplasia					0.82[a]		0.69[a]	0.69[a]	0.68[a]			
Overall fragmentation										0.50[a]	0.50[a]	
Overall OC fragment						0.76[a]				0.57[a]	0.57[a]	
C5-C6 increase size		1[b]										
C5-C6 remodeling			0.59[b]				0.51[a]	0.51[a]				
C6-C7 increase size				0.86[b]			0.53[b]	0.53[b]				
C6-C7 dysplasia							0.50[a]	0.50[a]				1[a]
C6-C7 fragmentation										0.50[a]	0.50[a]	
C7-T1 increase size								0.90[a]				
C7-T1 dysplasia								0.61[a]				
C7-T1 fragmentation											1[a]	

[a] Phi coefficient
[6] Cramer's V coefficient

Beccati F, *et al. Vet Rec* 2020;0:1–11. doi: 10.1136/vr.105756

Supplementary table 5. Results of the univariable analyses performed in horses with neck pain (*group C*) and spinal ataxia (*group A*).

Variables	***Group C***			***Group A***		
	OR	**95% CI**	**p-value**	**OR**	**95% CI**	**p-value**
Age	0.976	0.917-1.038	0.43	**0.907**	**0.82-1.00**	**0.07***
Sex						
Male	Ref	1		Ref	1	
Female	0.48	0.20-1.14	0.09	0.62	0.24-1.62	0.33
Breed						
Arab	Ref			Ref	1	
Warmblood	2.07	0.60-7.13	0.24	3.69	0.43-31.38	0.23
Thoroughbred	3.00	0.60-14.86	0.18	**18.00**	**1.83-177.15**	**0.01***
Other	2.33	0.52-10.47	0.27	9.33	0.97-90.02	0.05
Discipline						
Endurance	Ref	1		Ref	1	
Racing	3.85	0.76-19.46	0.10	**22.00**	**2.18-221.80**	**0.009***
Sport Competition	1.94	0.56-6.71	0.29	3.75	0.44-31.74	0.22
Other	1.22	0.28-6.31	0.81	4.88	0.46-51.83	0.18
AVL-C6						
No	**Ref**	**1**		**Ref**	**1**	
Yes	**3.38**	**1.27-8,96**	**0.01***	**3.81**	**1.31-11.06**	**0.01***
Overall increase size						
No	Ref	1		Ref	1	
Mild	1.16	0.32-4.20	0.81	1.12	0.34-3.68	0.85
Moderate	2.84	0.97-8.32	0.06	0.875	0.25-3.01	0.83
Severe	**9.00**	**2.78-29.13**	**<0.001***	3.20	0.92-11.11	0.07
Overall remodeling						
No	**Ref**	**1**		Ref	1	
Yes	**3.75**	**1.51-9.28**	**0.004***	1.85	0.73-4.66	0.19
Overall dysplasia						
No	Ref	1		Ref	1	
Yes	2.44	0.64-9.23	0.18	1.78	0.37-8.55	0.46
Overall fragmentation						
No	Ref	1		Ref	1	
Yes	7.59^{e-7}	0.000-∞	0.99	4.13^{e+7}	0.000-∞	0.98
Overall fragment						
No	Ref	1		Ref	1	
Yes	2.65^{e-7}	0.000-∞	0.98	3.83^{e+7}	0.000-∞	0.99
C5-C6 increase size						
No	Ref	1		Ref	1	
Mild	2.16	0.68-6.82	0.19	1.28	0.30-5.50	0.73
Moderate	**4.32**	**1.33-13.97**	**0.01***	**4.20**	**1.18-14.89**	**0.02***
Severe	1.244^{e+7}	0.000-∞	0.98	1.73^{e+7}	0.000-∞	0.99
C5-C6 remodeling						
No	**Ref**	**1**		**Ref**	**1**	
Yes	**3.42**	**1.44-8.11**	**0.005***	**2.75**	**1.04-7.30**	**0.04***
C5-C6 dysplasia						
No	Ref	1		Ref	1	
Yes	2.56^{e-7}	0.000-∞	0.99	3.89^{e-7}	0.000-∞	0.99
C5-C6 fragmentation						
No	NA	NA		NA	NA	
Yes			-			-
C5-C6 OC fragment						
No	Ref	1		Ref	1	
Yes	8.83^{e-7}	0.000-∞	0.99	3.82^{e+7}	0.000-∞	0.99
C6-C7 increase size						
No	Ref	1		Ref	1	
Mild	0.74	0.20-2.79	0.66	1.12	0.34-3.68	0.85
Moderate	2.24	0.78-6.38	0.13	0.93	0.26-3.23	0.91
Severe	**6.30**	**2.09-18.96**	**0.001***	2.80	0.83-9.46	0.09
C6-C7 remodeling						
No	Ref	1		Ref	1	
Yes	**2.51**	**1.10-5.70**	**0.02***	1.54	0.63-3.76	0.34
C6-C7 dysplasia						
No	Ref	1		Ref	1	
Yes	4.10	0.76-22.17	0.10	3.69	0.58-23.39	0.16
C6-C7 fragmentation						
No	Ref	1		Ref	1	
Yes	7.58^{e-7}	0.000-∞	0.99	4.13^{e+7}	0.000-∞	0.98
C6-C7 OC fragment						
No	Ref	1		Ref	1	

Yes	2.52^{e-7}	0.000-∞	0.99	1.37^{e+7}	0.000-∞	0.99
C7-T1 increase size						
No	Ref	1		Ref	1	
Yes	**5.10**	**1.38-18.84**	**0.01***	2.73	0.54-13.66	0.22
C7-T1 remodeling						
No	Ref	1		Ref	1	
Yes	3.33	0.95-11.70	0.06	2.14	0.45-10.08	0.33
C7-T1 dysplasia						
No	Ref	1		Ref	1	
Yes	3.18	0.49-20.25	0.22	1.65	0.14-19.47	0.68
C7-T1 fragmentation						
No	Ref	1		NA	NA	NA
Yes	1.17^{e+7}	0.000-∞	0.99			
C7-T1 OC fragment						
No	Ref	1		NA	NA	NA
Yes	1.17^{e+7}	0.000-∞	0.99			
C7-T1 size						
Smaller	Ref	1		Ref		
Same	2.47	0.89-6.86	0.08	1.06	0.28-3.92	0.92
Bigger	2.92	0.63-13.39	0.16	1.73	0.27-10.71	0.55

AVL-C6 = abnormal ventral lamina C6

* numbers in bold represent significant difference ($p<0.05$)