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Radiographic anatomy of the articular process joints of the caudal cervical vertebrae in the horse on lateral and oblique projections

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Summary

Reasons for performing study: **Plain radiography is the standard imaging technique for investigation of diseases associated with the articular process joints (APJ) of the caudal neck; however, the radiographic anatomy of these structures on both lateral and oblique radiographic projections has not previously been described in detail.**

Objectives: **To determine the optimal technique for obtaining oblique radiographs of the APJ of the caudal cervical vertebrae (C4-5, C5-6 and C6-7) and to provide a detailed description of their normal radiographic appearance, on both lateral and oblique radiographic projections.**

Methods: **Radiopaque markers were used to highlight the contours of the APJ on both lateral and oblique radiographs. A novel cineradiographic technique was employed to determine the optimal oblique projection to permit both left and right APJ to be assessed on the same radiograph. Lateral and oblique radiographs of the caudal neck were obtained in 6 live horses under standing sedation to assess the feasibility of the technique.**

Results: **The radiopaque markers facilitated identification of the APJ by clearly outlining the margins of the cranial and caudal articular processes on lateral and oblique radiographs. The optimal range of angles for obtaining oblique radiographs was 50–55° for C4-5, 45–55° for C5-6 and 45–55° for C6-7. Obtaining oblique radiographs within the specified range of angles resulted in a consistent radiographic image of the APJ in the caudal cervical region in the live individual.**

Conclusions and potential relevance: **The description of the normal radiographic anatomy of the cervical APJ of the caudal neck region in horses provides a valuable reference for the interpretation of cervical radiographs. Using the standardised technique to obtain oblique radiographs of the equine cervical vertebrae may provide additional diagnostic information about the APJ.**

Introduction

Paired synovial articulations are present between opposing articular processes of adjacent vertebrae in the cervical, thoracic and lumbar spine of the horse; however, their configuration varies between these anatomical locations. In the cervical region (caudal to the atlantoaxial articulation) the articular processes are large and obliquely orientated in the horizontal plane. The oval shaped, almost flat opposing articular surfaces form plane joints that allow movements parallel to the articular surfaces (Sisson 1975; Nickel *et al*. 1986; Clayton and Townsend 1989). The orientation of the articular processes influences the amount and type of movement of the joints, which is predominately dorsoventral flexion/extension and lateral bending in the caudal cervical spine.

Diseases of the cervical articular process joints (APJ) including osteoarthritis, osteochondrosis or fractures are a significant source of morbidity in horses (Rooney 1969; Powers *et al*. 1986; Stewart *et al*. 1991; Moore *et al*. 1992, 1994; Ricardi and Dyson 1993; Mayhew 1999; Levine *et al*. 2007).

Osteoarthritis of the cervical APJ plays an important role in the pathogenesis of cervical vertebral compressive myelopathy (CVCM). Enlargement of the articular processes due to osteophyte formation and/or hypertrophy of the periarticular soft tissues contributes to the development of static spinal cord compression (CVCM *Type II*), which tends to occur in older horses at the articulations of C5/C6 and C6/C7 (Powers *et al*. 1986; Moore *et al*. 1992; Mayhew *et al*. 1993; Trostle *et al*. 1993; Tomizawa *et al*. 1994; Mayhew 1999; Levine *et al*. 2007, 2008; van Biervliet 2007).

Enlargement of the articular processes has also been shown to cause spinal nerve root compression at the level of the intervertebral foramen, resulting in clinical signs of peripheral neuropathy including localised sweating, pain, stiffness, reluctance to bend the neck and forelimb lameness (Moore *et al*. 1992; Ricardi and Dyson 1993; Marks 1999). Additionally, osteoarthritis of the caudal cervical APJ may contribute to reduced performance and subtle hindlimb gait abnormalities such as stumbling or knuckling (Dyson 2003; Grant and Martinelli 2003; Piercy and Schwarz 2006; Maher *et al*. 2008).

Plain radiography is the primary imaging modality utilised in routine screening for osseous abnormalities of the cervical spine in the horse and a standard technique has been described previously (Whitwell and Dyson 1987; Butler *et al*. 2008). Routinely, this is performed with the horse standing and is limited to lateral-lateral projections (Whitwell and Dyson 1987; Butler *et al*. 2008). Interpretation of cervical radiographs can be challenging due to the

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complex radiographic anatomy and overlap of structures on either side of the neck. Furthermore, because radiographs are 2D presentations of 3D structures, clinically significant lesions may be inadequately visualised when radiographs are obtained in one plane only. This limitation is illustrated in the difficulty in detecting axial enlargement of the articular processes on plain lateral-lateral radiographs (Butler *et al.* 2008).

Ventrodorsal radiographs can be useful for examination of the cervical vertebrae in foals (Griffin *et al.* 2007); however, obtaining diagnostic quality ventrodorsal radiographs of the caudal cervical region in mature individuals is difficult, even with the horse positioned under general anaesthesia (Papageorges *et al.* 1987; Whitwell and Dyson 1987; Ricardi and Dyson 1993). Oblique radiographs have been utilised to assist in the detection of fractures of the cervical vertebrae (Nixon 1996; Sysel *et al.* 1998) and it has been suggested that these could potentially be used to identify axial enlargement of the APJ, which could be associated with lateral compressive lesions of the spinal cord (Moore *et al.* 1992). However, to the authors' knowledge, a standardised technique for obtaining oblique radiographs of the equine cervical spine and the normal radiographic anatomy of the APJ on oblique radiographic projections has not previously been published.

The objectives of this study were to provide a detailed description of the normal radiographic anatomy of APJ of the caudal cervical region on both lateral and oblique projections and to determine the optimal technique for obtaining oblique radiographs of the caudal cervical region in live horses.

Materials and methods

Animals

Necks from 12 skeletally mature horses aged 4–16 years (median 9.5 years) of various breeds (7 Thoroughbred or Thoroughbred cross, 2 Warmblood, 2 Welsh Cob and 1 Clydesdale) were obtained immediately following euthanasia. All horses had been subjected to euthanasia on humane grounds for reasons unrelated to pathology of the cervical region.

The necks were sectioned at the atlanto-axial joint and at the junction of the first and second thoracic vertebrae. The first ribs were transected at the level of the vertebral body and the superficial musculature was removed, leaving the ligamentous structures between each of the vertebrae intact. Particular care was taken not to incise the joint capsules of the APJ. After dissection, each vertebral column was suspended in axial alignment in a refrigerated room for up to 48 h prior to the radiographic examination.

For the live horse study 5 mature horses, age range 6–14 years, and one yearling were examined (3 Warmblood, 2 Thoroughbred and one Thoroughbred cross). These horses were presented to the Weipers Centre Equine Hospital for investigation of poor performance, stiffness or trauma to the neck and required lateral-lateral and oblique radiographs of the cervical region to exclude the presence of radiographic abnormalities of the cervical vertebrae.

Fig 1: Photograph of boiled out osseous specimens of C5–C7 that have been sectioned on the sagittal midline. Cranial is to the left. a) Abaxial surface. The ventral lamina of the transverse process of C6 is highlighted (arrow). b) Axial surface. Felt has been placed between vertebrae to maintain the space occupied by the intervertebral disc.

a)

b)

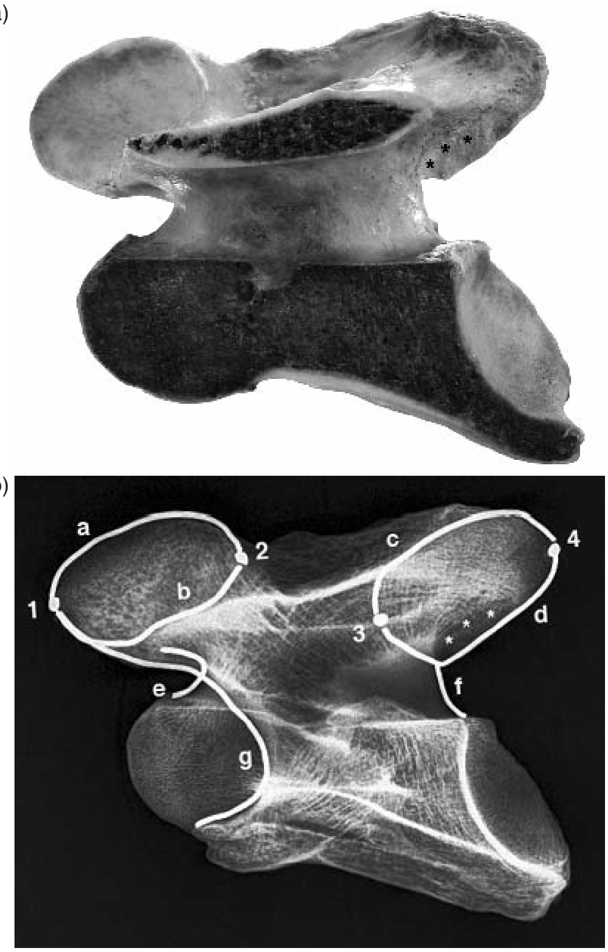

*Fig 2: a) Photograph of a sagittal section of a boiled out osseous specimen of C6 (axial surface). Cranial is to the left. b) Radiograph of the C6 specimen (pictured above). Radiopaque markers have been placed at the most cranial and caudal limits of the cranial (1 and 2) and caudal (3 and 4) articular processes. Wires highlight the abaxial (a) and axial margins (b) of the cranial articular process; the abaxial (c) and axial (d) margins of the caudal articular process; the cranial (e) and caudal (f) vertebral notches, and the ventral surface of the cranial articular process and contour of the cranial margin of the transverse process (g). A radiolucent region was observed on the axial surface of the caudal articular process in several specimens (*** in both figures).*

a)

b)

c)

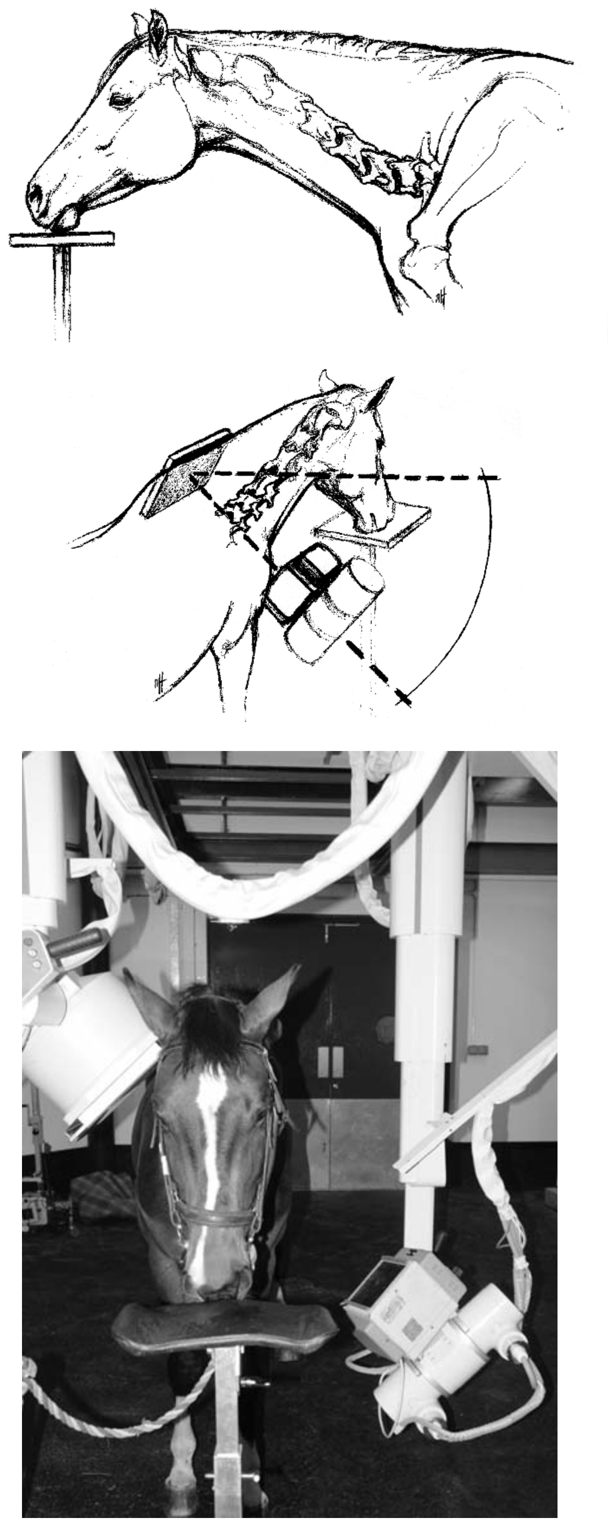

Fig 3: Radiographic technique for obtaining oblique radiographs of the caudal cervical spine. a) The neck should be aligned in the sagittal plane with the head supported on a stand at approximately shoulder height. b) The x-ray beam must be perpendicular to the sagittal plane and angled from the horizontal plane in a latero-ventral to latero-dorsal direction. The cassette is rested against the crest of the neck and angled perpendicular to the x-ray beam. c) The patient is observed from in front to achieve correct dorso-ventral positioning of the cassette and to confirm that the cassette is aligned perpendicular to the x-ray beam. In this study the x-ray tube and cassette holder were linked via an overhead gantry, which ensured that they were aligned in a cranio-caudal direction.

Equipment

Computed radiographs (CR MD 4.0 cassettes[1], CR 35X digitiser[2]) were obtained using a gantry mounted x-ray unit (85 kW generator[3] and matched tube[4]). Movement of the cassette holder was synchronised with the x-ray tube via an overhead gantry. All data were stored in DICOM 3[4] standard format and images were reviewed on a medical diagnostic imaging display screen[5]. The cineradiographic study was performed using the Ziehm Vario 3D C-arm[6] and the cine-loops were reviewed on a dedicated workstation[6].

Anatomical and radiographic study

A preliminary radiographic study was performed to exclude specimens with marked radiographic abnormalities of the cervical process joints, such as gross enlargement, fractures or osteochondritis dissecans fragments.

Each cervical column was aligned in a neutral position, similar to a horse standing with the head lowered to the level of the shoulder (see online supplementary information at www.evj.co.uk/suppinfo; Fig o1). Cranially the specimens were suspended from a wire placed through the dorsal spinous process of the second cervical vertebra (C2) and caudally by a wire placed through the dorsal spinous process of the first thoracic vertebra (T1). For each specimen a series of radiographs was obtained from both left and right sides. Radiographs were centred for each of the articulations of interest (C4-5, C5-6, C6-7) and correct radiographic positioning and perpendicular alignment of the X-ray beam were monitored by fluoroscopy. A film-focus distance of 100 cm and an object-film distance of 20 cm (measured from the sagittal midline) were used. Following the initial radiographic examination all specimens were boiled out to remove the remaining soft tissues and degreased with acetone.

Cervical vertebrae from 6 of the boiled out specimens were sectioned along the sagittal midline using a band saw and used to study the radiographic contours of the fourth to seventh cervical vertebrae in the absence of overlap from contralateral structures (Fig 1). Radiographs were obtained before and after placement of malleable wires to highlight the anatomical structures of interest, including the articular margins of the cranial and caudal cervical articular processes; the cranial and caudal vertebral notches (of the intervertebral foramina) and the cranial margin of the transverse processes (Fig 2). Small radiopaque markers were placed at the most cranial and caudal extremities of the articular processes to help distinguish between the axial and abaxial margins.

The boiled out cervical vertebrae from the remaining 6 specimens were suspended in anatomical alignment with the aid

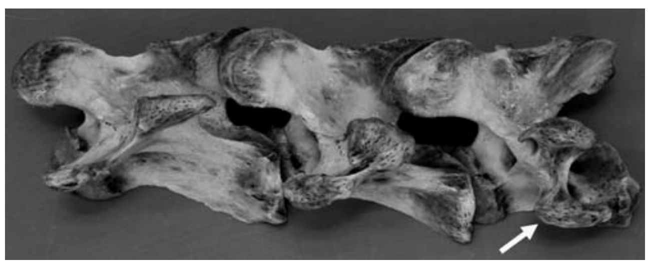

Fig 4: Photograph of boiled out osseous specimens of C5–C7 (abaxial surface). Cranial is to the left. The vertebrae have been sectioned on the sagittal midline. Note the ventral lamina of the transverse process of C6 is transposed onto C7 on the left side (arrow). The right side was normal.

of an elasticated cord placed through the vertebral canal. Radiolucent adhesive felt[7] was placed between the vertebral bodies to replicate the intercentral joint space and radiopaque spherical markers of known diameter were placed on the cranial tubercle of the transverse process of C6 on each side of the vertebra to highlight the effect of radiographic magnification (Moore *et al*. 1994). Lateral-lateral radiographs were obtained from both sides.

Cineradiographic C-arm study

The 6 intact boiled out specimens were used to study the radiographic appearance of the cervical process joints in oblique radiographic projections and to determine the optimal x-ray beam angle for obtaining oblique radiographs. The optimal radiographic angle was defined as the angle of the x-ray beam from the horizontal plane, which permitted both the left and right APJ to be evaluated simultaneously on the same radiograph and allowed the axial aspect of the joints to be visualised. The vertebrae were suspended in anatomical alignment as previously described (Supplementary info; Fig o2). The Ziehm Vario 3D C-arm was centred independently for each region of interest (C4-5, C5-6 and C6-7) and positioning was confirmed using fluoroscopy. An isocentric scan was performed using a fully automated elliptical C-arm path, which maintained a fixed object-image intensifier distance of 20 cm. The region of interest remained at the centre of the image during the entire isocentric image acquisition cycle, which comprised 110 fluoroscopic images acquired over a range of 0–135° starting from the lateral position (0°). Each image series was stored digitally and could be reviewed as continuous cine-loop or replayed frame by frame. For each individual frame the angle of the x-ray beam from the lateral position was automatically displayed.

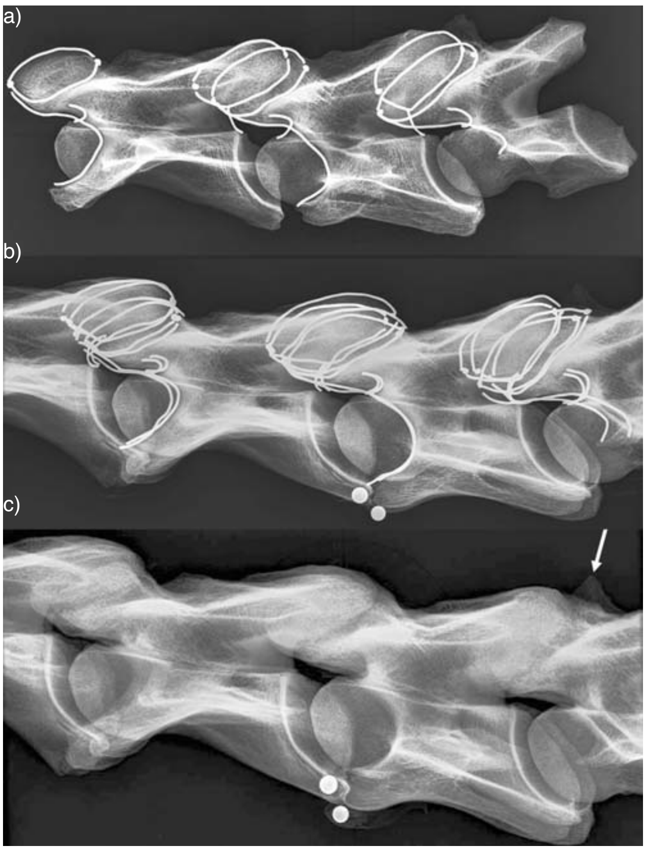

Fig 5: Lateral radiograph of boiled out osseous specimens C5–C7, centred on the C5/6 articulation. Cranial is to the left. a) Sagittal sections of vertebrae with wire markers. b) Intact vertebrae with wire markers. c) Intact vertebrae. Dorsal spinous process of C7 (white arrow). In (b) and (c) identical spherical markers of a known diameter have been placed on either side of the neck at the cranial aspect of the transverse processes of C6. These markers highlight the effect of magnification between the left and right sides. In (c) the dorsal spinous process of C7 is highlighted (white arrow). This should not be misinterpreted as enlargement of the APJ.

Live standing horses

The horses were sedated and positioned with the thoracic limbs placed just behind the vertical plane; the neck was extended in the sagittal plane and the head rested on a stand at shoulder level (Fig 3a). Lateral-lateral radiographs were centred independently for the C4-5, C5-6 and C6-7 APJ using standard radiographic technique (Butler *et al*. 2008). Left-ventral to right-dorsal and right-ventral to left-dorsal (lateral oblique) radiographs of the caudal cervical region were centred at the level of the transverse process of the more cranial vertebra (C4, C5, C6) of the joint to be examined; the transverse processes were palpable in all cases. The cassette was supported against the crest of the neck in the gantry-mounted holder so that it was positioned perpendicular to the x-ray beam (Fig 3b). The cassette holder was linked to the x-ray tube via an overhead gantry ensuring that they were aligned in a cranio-caudal direction and the patient was observed from in front to achieve correct dorso-ventral positioning of the cassette (Fig 3c). Increased collimation of the x-ray beam was achieved using a lead sheet placed on the upper margin of the light beam diaphragm. The exposure factors varied from 75–95 kV and 10–25 mAs, depending on the size of the horse and the cervical muscle mass. Identical exposure variables were used for both the lateral and oblique projections.

Results

Examination of the boiled out cervical vertebrae revealed minor morphological variations between specimens; however, in the articular processes joints included in the study, gross pathological changes were not identified. Mild asymmetry was observed between the left and right articular processes in some individual vertebrae and mild modelling of the articular process margins was considered to be present in most specimens. These findings were not discernable radiographically.

Four of the 12 specimens demonstrated normal variation in the anatomy of C6. In 3 specimens the ventral lamina of the transverse process of C6 was transposed onto C7 on one side (Fig 4) and in one specimen the ventral laminae of both transverse processes of C6 were absent.

The contours of the articular processes were clearly highlighted in radiographs of hemivertebrae and intact vertebrae by wire markers; these images were compared to radiographs of the intact vertebra without markers (Fig 5). The wire markers clearly demonstrated the radiographic superimposition of the articular processes of intact vertebrae and the radiopaque markers placed on each transverse process illustrated the difference in size between each side due to the effect of radiographic magnification (mean difference of 11%).

On ‘true’ lateral radiographs of intact vertebrae the dorsal *lamina* had a discrete radiopaque contour (A and B, Fig 6b) and the

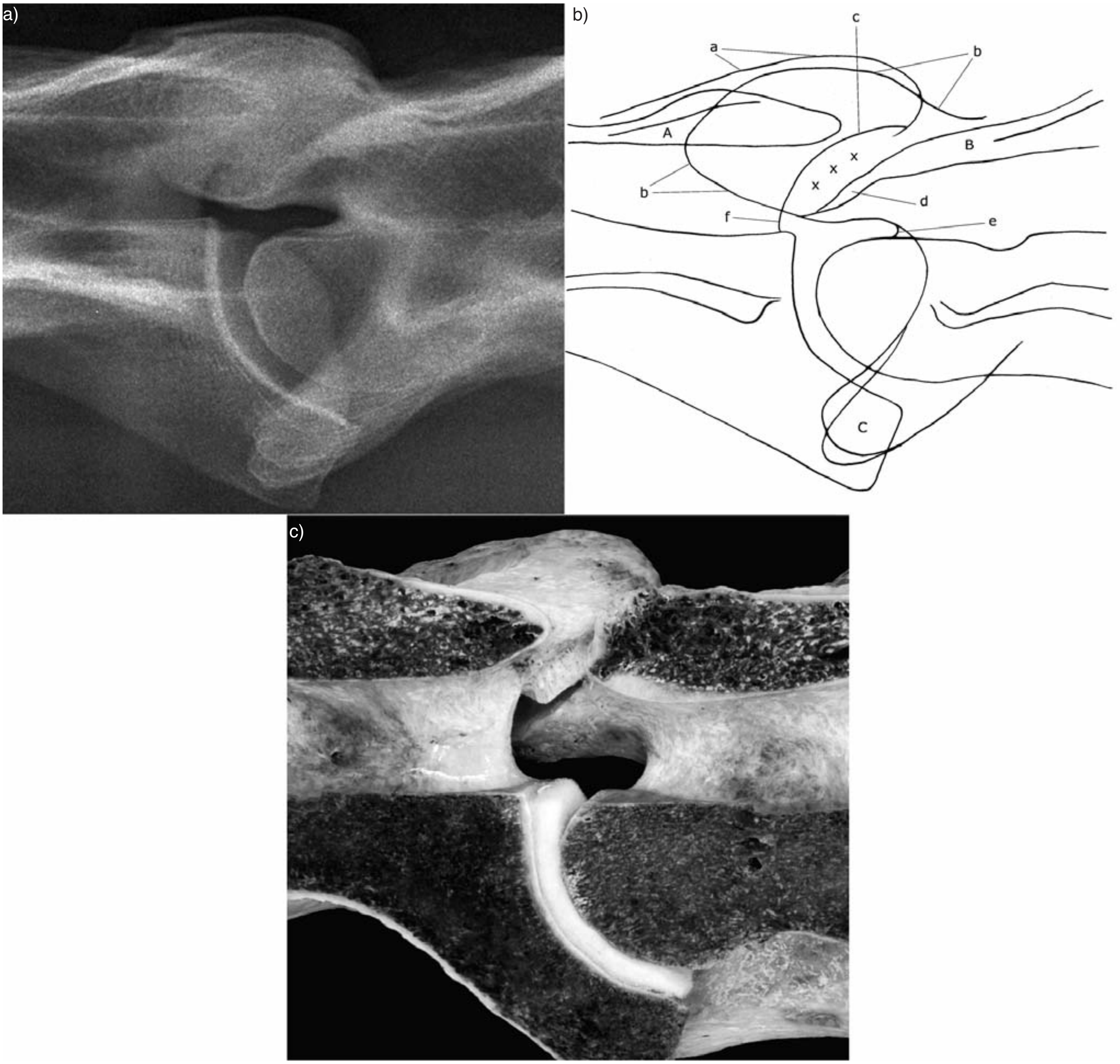

Fig 6: a) Lateral-lateral radiograph of a 10-year-old Thoroughbred gelding. The radiograph is centred on the C4/5 articulation. Cranial is to the left. b) Line diagram of the C4/5 articulation shown in the radiograph in Fig 6a. The radiographic contours are labelled: Dorsal lamina of C4 (A), and C5 (B). Cranial tubercle of C5 transverse process (C). Abaxial margins of caudal articular process of C4 (a) and C5 (b). The crescent shaped radiolucent region is marked xxx, its dorsal contour (c) and ventral contour (b). Cranial vertebral notch of C5 (e). Caudal vertebral notch C4 (f). c) Photograph of the axial surface of boiled out osseous specimen of C5-C6 that has been sectioned on the sagittal midline. Cranial is to the left. The distinctive groove extending along the axial surface of the caudal articular process of C5 corresponds to c in the line diagram.

outlines of the left and right vertebral notches were closely aligned (e and f, Fig 6b). Cranial to the dorsal vertebral lamina the superimposed axial margins of the cranial articular processes were visualised as a discrete radiopaque contour coursing cranio-ventrally (d, Fig 6b).

Superimposition of the axial margins of the caudal articular processes was observed as a discrete radiopaque contour coursing dorso-caudally from the caudal vertebral notch. A region of relative radiolucency was identified between the contours of the axial margins of the cranial and caudal articular processes. In some specimens a distinctive crescent shaped radiolucent region was observed overlapping the caudal articular process (c, Fig 6b). Direct comparison between radiographs of the hemivertebrae to the boiled out specimens revealed that this radiolucent region was consistent with a groove on the axial border of the caudal articular process, which extended dorsocaudally from the caudal vertebral notch (Fig 6c).

On radiographs of the intact vertebrae the abaxial margins of the articular processes were difficult to identify without the aid of radiopaque wires. Small radiopaque markers highlighted the cranial and caudal extremities of the articular processes; however, on plain radiographs only the superimposed cranial extremities of the cranial articular processes and the caudal extremities of the caudal articular processes could clearly be appreciated.

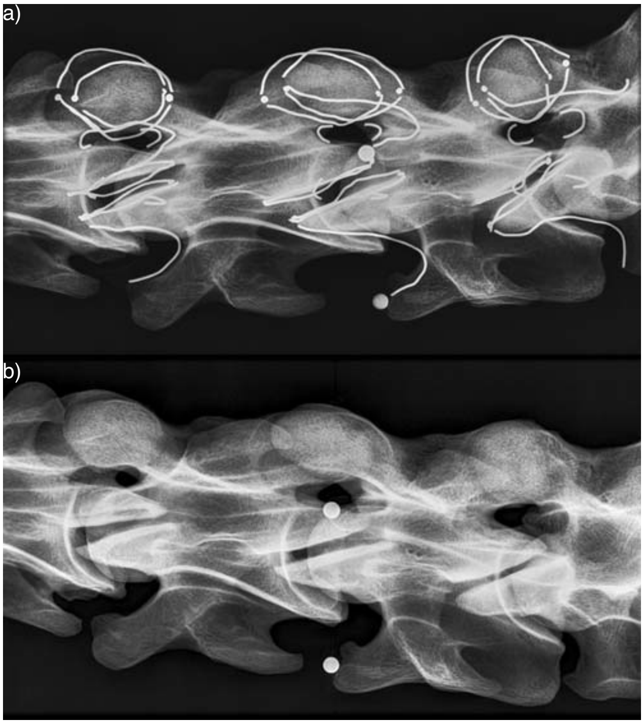

Fig 7: Left-(50°)ventral to right-dorsal radiograph of boiled out osseous specimen of C4–C7 centred on the C5/6 articulation. Cranial is to the left. a) Osseous specimens with wires placed as shown in Figure 2. b) Osseous specimens without wires. Identical spherical markers were placed on the cranial aspect of the transverse processes on either side of the C6 vertebra. The left articular process joint and transverse process are projected dorsally (side closer to the x-ray tube). The right articular process joint and transverse process are projected ventrally (side further from the x-ray tube).

In all specimens the seventh cervical vertebra had a dorsal spinous process, which varied in morphology. On radiographs, the dorsal spinous process had a variable radiopacity and was observed superimposed over the caudal aspect of the articular process joint (arrow, Fig 5c).

Oblique radiographs and C-arm study

In this study oblique radiographs of the caudal cervical vertebrae were obtained from left-ventral to right-dorsal or from right-ventral to left-dorsal. On the projection shown in Figure 7 (left-ventral to right-dorsal) the articular process joint of the side closer to the x-ray machine was projected dorsally (left joint) and the articular process joint of the side further from the x-ray machine was projected ventrally (right joint), where it was superimposed over the vertebral bodies and intercentral joint of the adjacent vertebrae. Wires were useful in identifying the radiographic contours of the articular processes on oblique projections. The 'iso-loop' conveyed a 3D-like image impression of the vertebrae and provided an easy and reliable way to identify overlap of the radiographic contours of the APJ on projections of varying obliquity (online supplementary information: cineloops C5-6.mov and C6-7.mov. See www.evj.co.uk/suppinfo). Using this technique both APJ were most clearly visualised using projections of 50–55°(C4-C5); 45–55° (C5-C6) and 45–55° (C6-7) from the horizontal plane.

Live horse study

In the live horse both APJ were clearly visualised on lateral oblique radiographs. Images obtained were comparable to those from the cadaver study; however, radiographic contours were less clearly

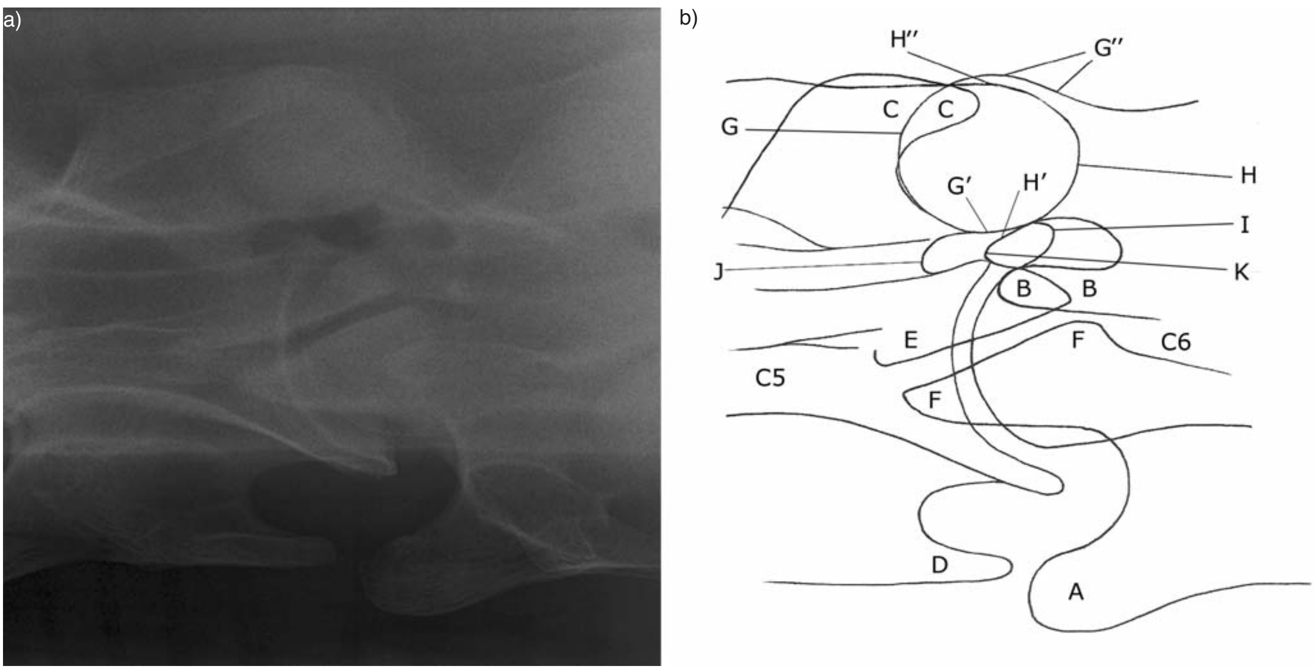

Fig 8: a) Left- 50°ventral to right-dorsal oblique view of the caudal cervical region in an 8-year-old Thoroughbred gelding. The radiograph is centred on the C5/6 articulation and cranial is to the left. b) Line diagram demonstrating the radiographic contours identified in (a). The radiographic contours are labelled: Cranial tubercle of right (A) and left (B) transverse process of C6. Caudal tubercle of left (C) and right (D) transverse process of C5. Right caudal articular process of C5 (E) and cranial articular process of C6 (F). Left cranial articular process of C6 (G) with its axial (G') and its abaxial (G'') margins. Left caudal articular process of C5 (H) with its axial (H') and its abaxial (H'') margins. Cranial vertebral notch of C6 (I). Caudal vertebral notch of C5 (J). Junction between left and right caudal articular processes of C5 (K).

defined due to the effect of increased radiopacity of the soft tissues. Resting the head on a stand and extending the neck so that the head was at shoulder level was important in achieving consistent results (Fig 8). The horses stood well and tolerated having the cassette rested against the crest.

Discussion

The approach of using wire markers in cadaver specimens enabled the complex radiographic appearance of the APJ of the caudal cervical spine of the horse to be accurately correlated with anatomical features of the joints. While this information should be of value to the interpretation of radiographs of the cervical spine, it also confirmed previous observations regarding the limited visualisation of the APJ in lateral-lateral radiographs (Butler *et al*. 2008).

Improved visualisation of the APJ was achieved using oblique radiographic projections, allowing both APJ to be visualised on the same radiograph. The novel cineradiographic technique used in this study permitted the varying radiographic appearance of the APJ on different oblique projections to be compared. The oblique radiographic projections of the caudal cervical APJ were successfully obtained in a number of clinical cases; the descriptions of radiographic anatomy made from cadaver specimens were applicable to the live horse.

On lateral-lateral radiographs of the intact vertebrae the obliquely orientated region of relative radiolucency observed coursing from caudo-dorsally to cranio-ventrally across the APJ has previously been referred to as the ‘joint space’ (Whitwell and Dyson 1987; Dik and Gunsser 1990). Radiopaque wires were used successfully to demonstrate that the ventral contour of this radiolucent region corresponded to the outline of the superimposed axial articular margins of the cranial articular processes. The dorsal margin of the radiolucent region was continuous with the outline of the caudal vertebral notch and had 2 distinctive radiographic appearances. Typically, it corresponded to the superimposed axial margins of the caudal articular processes and appeared as a discrete radiopaque contour coursing parallel to the ventral margin. In some cases, however, the dorsal margin had a crescent shaped outline. Examination of the boiled out specimens revealed that this region corresponded to superimposition of caudal articular processes, which had a prominent grooved profile of their axial surface. The description of the radiographic appearance of the axial margins of the articular processes should be of interest to clinicians because irregularity of these contours may be present if there is osteophyte formation at the axial margins of the articular processes; a finding that is likely to be of clinical significance in horses showing signs of ataxia (Whitwell and Dyson 1987; Moore *et al*. 1992).

Severe axial enlargement of the APJ due to osteophyte formation can cause lateral compression of the spinal cord; however, on lateral-lateral radiographs of the cervical region, superimposition of the osseous structures results in poor differentiation of the margins of the articular processes and an inability to discriminate between the left and right APJ. It has been suggested that radiographic examination from both sides of the neck can help to determine on which side of the neck a unilateral lesion is present because the lesion is smaller and more clearly visible when closer to the cassette (Dyson 2003; Butler *et al*. 2008). However, this technique provides no additional information regarding the morphology of the individual APJ or lesions affecting their axial margins.

In contrast, lateral oblique projections facilitate visualisation of both the left and right APJ on the same radiographic projection. The cine-loop studies obtained using the C-arm facilitated identification of the x-ray beam angle, which allowed the optimal visualisation of the APJ on either side of the neck. In this study the specific requirements of the oblique radiographic projections were that the x-ray beam had to be tangential to the joint space of the articular process joint of the side further from the x-ray machine to permit better assessment of its width and regularity. In addition the axial margin of the articular process joint and the intervertebral foramen of the side closer to the x-ray machine needed to be easily identified. In the cadaver study there was a range of oblique views in which these requirements were met for each of the joints studied.

Lateral-oblique radiographs were consistently obtained in live standing horses and were similar to those obtained in the cadaver study. There was a learning curve to achieving the ideal radiographic technique in the live animal. Movement of horses was minimised by ensuring they were comfortably positioned using sedation and resting the head on a stand placed at approximately shoulder height. Close collimation of the x-ray beam to the area of interest was used to minimise scattered radiation.

Due to the large muscle mass present in the caudal cervical region relatively large x-ray exposure settings are required to produce radiographs of sufficient diagnostic quality. In our study we found that the radiographic settings used to obtain lateral projections were satisfactory for oblique projections.

The results of this work should enable clinicians to improve their understanding of the radiographic anatomy of the APJ of the caudal cervical spine of the horse, and thereby improve their interpretation of radiographs of this region. We suggest that lateral oblique radiographs could potentially be helpful for examination of the caudal cervical region in horses in which disease of the APJ is suspected, because they allow assessment of the left and right APJ independently and may therefore provide additional information otherwise not obtained from standard lateral views.

Further studies are warranted to investigate the use of lateral-oblique radiographs in horses with clinical signs attributed to osteoarthritis of the APJ of the caudal cervical spine.

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Manufacturers’ addresses

[1]Agfa-Gevaert, Brentford, Middlesex, UK.
[2]Digital Imaging and Communications in Medicine, Rosslyn, Virginia, USA.
[3]Communication & Power Industries, Georgetown, Ontario, Canada.
[4]Villa Systemi Medicali, Buccinasco, Italy.
[5]Barco, Kortrijk, Belgium.
[6]Ziehm imaging GmbH, Nuremberg, Germany
[7]Cuxson Gerrard & Co. Ltd, Oldbury, West Midlands, UK.

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