Journal of Equine Veterinary Science 116 (2022) 104054

Contents lists available at ScienceDirect

Journal of Equine Veterinary Science

journal homepage: www.j-evs.com

Review Article

A Systematic Review of Clinical Signs Associated With Degenerative Conditions and Morphological Variations of the Equine Caudal Neck

Nicole Kernot*, Raquel Butler, Hayley Randle

Charles Sturt University, Wagga Wagga, New South Wales, Australia

ARTICLE INFO

Article history:
Received 20 December 2021
Received in revised form 14 June 2022
Accepted 19 June 2022
Available online 2 July 2022

Keywords:
Caudal cervical
Malformation
Articular process joints
Stenotic myelopathy
Clinical signs

ABSTRACT

Conditions of the equine caudal neck (C5-C7) are thought to be associated with various clinical signs. However, little investigation has been undertaken to isolate clinical indicators associated with specific conditions of the equine caudal cervical spine. This systematic review aimed to evaluate associations of clinical signs with anatomical malformation of caudal cervical vertebrae, spinal cord compression of the caudal cervical spine, and arthropathy of the caudal cervical articular process joints (APJs). A literature search was carried out using Google Scholar in accordance with PRISMA (Preferred Reporting Items for Systematic reviews and Meta-Analyses) guidelines. Studies were selected for inclusion in this systematic review according to a set of inclusion criteria, resulting in a small group of eligible studies (n = 12) that addressed clinical signs associated with caudal cervical spine conditions in horses. The results of the included studies indicate that there are grounds for further investigation of clinical presentations of specific conditions of the equine caudal neck such as anatomical variations, myelopathy, and alteration to the APJs.

1. Introduction

The equine neck has evolved to facilitate movements and behaviors exhibited by the modern-day horse. The extensive musculature of the neck allows dorsoventral flexion and extension, lateral flexion, and rotation used in grazing, browsing, locomotion, and predator surveillance [1]. Zsoldos and Licka [2] describe a cantilever effect of the equine head and neck that facilitates locomotion and stability. Normal anatomy of the caudal cervical region is essential for optimal postural and locomotory functions of the equine neck [2]. Disorders of the caudal neck in horses may lead to compromise of neurological, biomechanical, and functional processes as well as cause pain, raising significant concerns for horse welfare if unrecognised and not managed.

A horse's neck comprises seven cervical vertebrae (C1-C7) [2]. The caudal cervical vertebrae (C5-C7) [3] possess processes that form attachment points for soft tissues [4]. The cranial and caudal articular processes are connected to adjacent vertebrae by paired synovial articular process joints (APJs) and intervertebral joints [5–7]. Figs. 1 and 2 display the morphology and articulation of the caudal cervical vertebrae. C5 has transverse processes comprised of dorsal and ventral tubercles, with large cranial and caudal articular processes [7]. C6 has paired ventral laminae, each of which possess cranial and caudal ventral tubercles [8]. C7 is shorter than the previous two vertebrae and has relatively small transverse processes [7]. In some cases, the caudal ventral tubercle (CVT) of C6 may be uni- or bi-laterally altered, absent, or transposed onto the ventral surface of C7 [8–12]. This condition, termed Equine Caudal Cervical Morphological Variation (ECCMV) [9], has been recorded as early as the 1920s [13], however its prevalence and potential implications have only recently been investigated [8,14]. Studies investigating the prevalence of ECCMV have yielded varying results, ranging from 13.3% to 43% [8,11,12,15,16], with a noticeably higher occurrence in Thoroughbreds [8] and Warmbloods [11,15].

Osteoarthritic alteration of the APJs of caudal cervical vertebrae has been reported as a degenerative condition [5,17] and is generally observed in older horses. Dyson [6] states that approximately 50% of mature horses have uni- or bi-lateral remodelling of the APJs between C6 and C7, often accompanied by excessive fibrocartilage and enlargement of the articular processes. Extensive bone proliferation and joint capsule thickening are likely to contribute to dorsolateral compression of the spinal cord [3,18], however some

Conflict of interest statement: There are no potential conflicts of interest regarding this submission.

Ethical statement: As this submission is a systematic review of existing literature, no primary research was conducted. There was no requirement for ethics approval and no procedures that involved subjects.

* Corresponding author at: Nicole Kernot, BEquineSc, School of Agricultural, Environmental, and Veterinary Sciences, Charles Sturt University, Wagga Wagga, NSW 2678, Australia.

E-mail address: nicicolek@outlook.com (N. Kernot).

https://doi.org/10.1016/j.jevs.2022.104054
0737-0806/

Fig. 1. Lateral view of equine caudal cervical spine. ⬮ caudal articular processes, ▲ cranial articular processes, ■ transverse processes, ★ articular process joints, a cranial ventral tubercle of C6, b caudal ventral tubercle of C6.

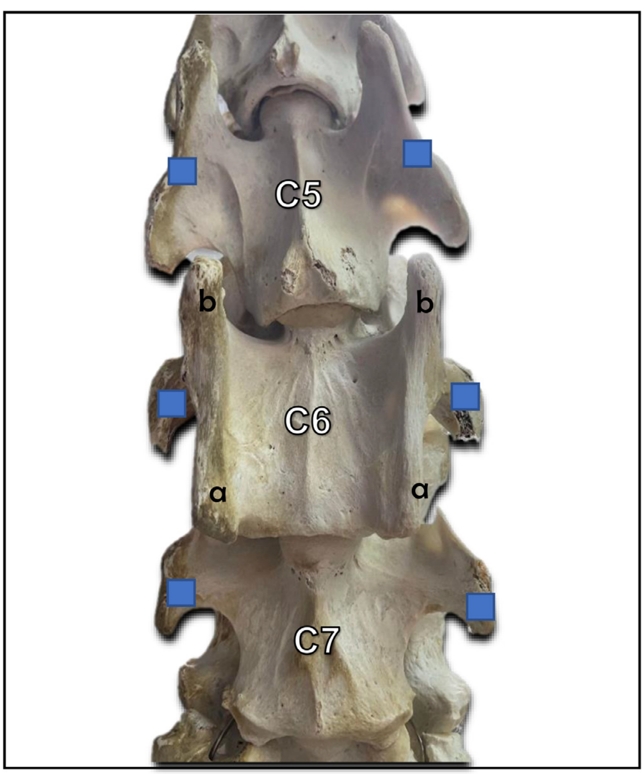

Fig. 2. Ventral view of equine caudal cervical spine. ■ transverse processes, a caudal ventral tubercle of C6, b cranial ventral tubercle of C6.

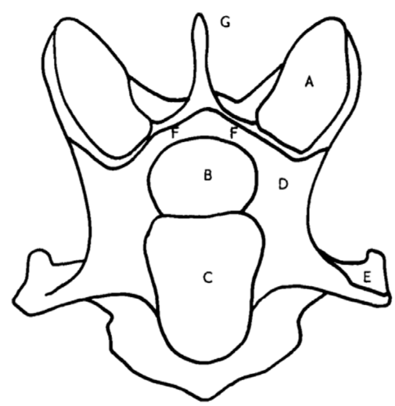

Fig. 3. Anatomy of C7, craniocaudal view. A, Facet of cranial articular process; B, Vertebral foramen; C, Head of vertebral body; D, Lateral vertebral arch or pedicle; E, Transverse process; F, Dorsal laminae forming dorsal arch; G, Spinous process [5].

enlargement and degeneration of articular processes and APJs are considered normal in ageing horses [3] and its clinical significance is currently unclear

The vertebral arch and body of each cervical vertebra form the vertebral foramen (B in Fig. 3), which houses the spinal cord [5]. Cervical vertebral stenotic myelopathy (CVSM) is a generalised condition associated with a narrowing of the cervical vertebral canal that results in compression of the spinal cord and causes progressive neurological symptoms such as ataxia and weakness [17–19]. Recorded incidences of CVSM includes 60% [20] and 67% in a group of neurologically impaired horses [21]. While the cause of CVSM is likely multifactorial, it may be due to or associated with ECCMV and/or APJ arthropathy [10,17,18].

The conditions described above (ECCMV, APJ arthropathy, and CVSM) may occur concurrently and have been suggested to be related [8,14,15,20 – 22]. Gough et al [20] identified CVSM and remodelling of the APJs in 61% and 98% respectively in the same group of 51 horses. ECCMV has been linked to CVSM by causing dorsoventral narrowing of the vertebral canal [18]. There is a large range of clinical signs that may be associated with caudal neck conditions. Ataxia, neck pain or stiffness, and neurological deficits have been associated with ECCMV [8,14,23,24], APJ arthropathy [14,20], and CVSM [6,17,21]. A base-wide forelimb stance, instabil-

Table 1
Inclusion criteria for eligible studies.

Inclusion Criteria	Rationale
Not a duplicate	Maintained correct representation of results, avoided duplicated data.
Written in English	Avoided incorrect interpretation of data and findings that may occur during translation [27].
Equine primary research study	This review aimed to associate clinical signs shown in horses with caudal neck conditions. While these problems may present in other species, they are irrelevant to this review. Only primary research was included to avoid misrepresentation and duplicated occurrences.
Published after 2001	Ensured relevant data and findings. Advances in diagnostic technology and knowledge of abnormalities are recent, so there was little use for older studies.
Peer-reviewed	For optimal validity of this review, only data collected in peer-reviewed studies was used. Peer-reviewed studies have reduced chance of methodological flaws and heighten validity [28].
Full article is accessible	Transparency of the materials, methods, results, and conclusions of each study are important to assess validity and relevance of data. Furthermore, there is a reported lack of consistency between abstract and subsequent peer-reviews results [29].
Relates to caudal cervical region	There are many possible conditions of the equine neck. This review only investigated those that occur in the caudal cervical region (C5-C7).
Records and defines occurrence of clinical signs associated with degenerative or anatomical conditions of the caudal neck	As this review aimed to identify the presence or absence of association between clinical signs and caudal neck conditions, it was not beneficial to include studies that did not clearly record and define clinical signs exhibited by horses with ECCMV, CVSM, or APJ alteration. To maintain focus on degenerative and anatomical caudal cervical conditions, the clinical signs of horses with trauma-induced pathology were not considered.

Abbreviations: APJ, articular process joint; CVSM, cervical vertebral stenotic myelopathy; ECCMV, equine caudal cervical morphological variation.

ity, and stumbling have been identified in horse diagnosed with ECCMV [23,24]. Gough et al [20] identified neck muscle atrophy, lameness and weakness in horses diagnosed with APJ arthropathy. Dyson [6] states that abnormal posture, gait abnormalities, and patchy sweating may also be associated with CVSM.

While it has been determined that horses presenting certain clinical signs such as ataxia and neck pain are significantly more likely to have caudal cervical abnormalities [14,15], there are currently no standard definitions of clinical presentations associated with specific conditions of the equine caudal neck. This may be due to an underestimated prevalence and severity within the industry, as well as lack of effective diagnostic capability for each condition. Increased ability of equine practitioners and veterinarians to recognise and understand these disorders has the potential to improve horse welfare and reduce wastage within the current equine industry [10,25]. Further investigation into causes, clinical indicators, implications, and diagnoses of caudal cervical spinal conditions is not only warranted, it is necessary to enhance safe and ethical practice within the equine industry.

The aim of this systematic review is to evaluate association of clinical signs with specific conditions of the equine caudal cervical spine, namely ECCMV, APJ arthropathy, and CVSM. A critical review of existing knowledge will aid in recognition of these conditions, promote standardisation of terminologies, and provide a sound basis for further research of equine caudal neck conditions.

2. Materials and Methods

An explicit and transparent approach to this systematic review ensures validity of its outcomes as a basis for further research. PRISMA guidelines, an evidence-based set of items to improve reporting in systematic reviews and meta-analyses [26], were applied throughout this review.

2.1. Data Sources and Searches

A set of keywords including “Boolean Operators” was determined by scrutiny of existing studies that address clinical signs of specific disorders of the equine caudal neck. Eligible studies possess the attributes featured in Table 1. Exclusion of studies was initially conducted using titles of the resulting studies. A second round of exclusion was conducted after papers were individually appraised.

2.2. Data Extraction

An overview of included study characteristics was laid out in Table 2. Inclusion of variables was based on PICOS [31] and adjusted to be relevant to the study designs of the included papers. The variables addressed were participants, study design, diagnostic methodology, and results relating to clinical signs.

Data were extracted independently by author NK without the use of automation tools to limit the risk of misinterpretation. Due to the lack of a clear relationship between clinical signs and ECCMV, few studies were expected to be eligible for inclusion. Varied methods of outcome measures were expected in each of the studies, necessitating independent data extraction for each individual study. A summary of findings relating to clinical signs from all studies were synthesised.

2.3. Risk of Bias

Due to the qualitative nature and observational study designs of some included studies in this review, existing risk of bias (RoB) tools were difficult to apply consistently. However, a novel RoB assessment (Table 3) adapted from the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) [30] checklist was carried out. Criteria from the STROBE checklist that could be applied to most included studies were considered, with additional factors that may contribute to risk of bias.

2.4. Data Analysis

Quantitative data were likely to be limited in result of this review due to the qualitative nature of some included studies. Qualitative thematic analysis software NVivo (v12) was utilised to identify frequency of themes only in the results section of each study. Occurrence of mentioned clinical signs, caudal cervical disorder types, and sites of abnormalities were recorded.

3. Results

A literature search was conducted in Google Scholar on February 25, 2022 that produced 189 results. The terms used were: equ OR horse AND caudal cervical AND clinical; anatomical variation; malformation; vertebrae; wobbler. Determination of eligible studies for inclusion were completed by author NK (Fig. 4). The results were screened to remove duplicates (n = 4) and publications prior

Table 2
Characteristics of included studies.

Study	Title	Subjects	Study Design	Diagnostic Methodology	Results (Relating to Clinical Signs)
Beccati et al. (2020) [14]	Radiographic findings and anatomical variations of the caudal cervical area in horses with neck pain and ataxia: case–control study on 116 horses	Clinical and radiographic records of horses subjected to cervical radiography between January 2006 and October 2018 were obtained from the Veterinary Teaching Hospital of University of Perugia. Study population (n = 166) included Warmbloods (WB) (n = 69, 59.5%), Thoroughbreds (TB) (n = 16, 9.6%), Arabs (n = 15, 9.0%), Anglo-Arabs (n = 7, 4.2%), Quarter horses (n = 3, 1.8%), Argentinians (n = 2, 1.2%), sport ponies (n = 2, 1.2%), Italian trotter (n = 1, 0.60%), and Paint horse (n = 1, 0.60%). Mean age was 7.5 (range 1–23) years, with geldings (n = 58), mares/fillies (n = 38), and stallions/colts (n = 20).	Observational retrospective case-control study	Computed or digital radiography	Anatomical variation of C6 (ECCMV) significantly increased the odds of showing neck pain [Odds ratio (OR) = 4.7] and ataxia (OR = 8.2). Horses with APJ enlargement were significantly more likely to exhibit neck pain (OR = 4.4–18.6 depending on severity) and ataxia (OR = 13.9).
Down and Henson (2009) [3]	Radiographic retrospective study of the caudal cervical articular process joints in the horse	Clinical and radiographic records of horses presented to The Queen's Veterinary School Hospital (1997–2007) for cervical investigation resulted in 137 horses. 15 were excluded due to pathology cranial to C5, therefore 122 were included. Mean age 8 yrs (range 8 mo to 25 yrs). Predominant breeds were TB (n = 42, 34.4%), TB cross (n = 32, 26.2%), and WB (n = 18, 14.8%). Included were geldings (n = 83, 68.0%), mares (n = 29, 23.8%), and stallions (n = 4, 0.03%). Six horses' genders were not specified.	Observational retrospective case study	Lateral radiographs	No significant association between presence and type of clinical signs and grades of enlargement according to Fisher's exact test.
Janes et al. (2014) [33]	Comparison of magnetic resonance imaging with standing cervical radiographs for evaluation of vertebral canal stenosis in equine cervical stenotic myelopathy	Thoroughbreds with CVSM (n = 19) identified based on clinical history, neurological assessment, cervical radiographs, and post-mortem examination. Mean age 18.1 (range 6–50) mo. 17 males, 2 females. Group of control Thoroughbreds (n = 9). Mean age 12.4 (range 9–67) mo. 6 males, 3 females.	Case control study	Radiographs, MRI, and post-mortem examination	Criteria for horses to be included in the CVSM group included (1) hindlimb ataxia and proprioceptive deficits, (2) narrowing of the cervical canal based on radiographically measured intravertebral or intervertebral minimal sagittal ratios, and (3) evidence of spinal cord compression on post-mortem investigation. Histopathologic evidence of caudal cervical spinal cord compression occurred at C5–C6 (n = 11), and/or C6–C7 (n = 6). The mean grade of ataxia across the CVSM group (n = 19) was 2 (range 1–4) in forelimbs and 3 (range 2–4) in hindlimbs.
Janes et al. (2015) [34]	Cervical vertebral lesions in equine stenotic myelopathy	Thoroughbreds with CVSM (n = 19) identified by based on clinical history, neurological assessment, cervical radiographs, and post-mortem examination. Mean age 18.1 (range 6–50) mo. 17 males, 2 females. Group of control Thoroughbreds (n = 9). Mean age 12.4 (range 9–67) mo. 6 males, 3 females.	Case control study	Lateral radiographs, MRI, post-mortem examination, micro-CT	14 of 19 (74%) of CVSM horses had histopathological localization of spinal cord compression at C5-C7. Mean neurologic examination grades for horses with caudal cervical spinal cord compression (n = 14) were 2 (range 1.5–4) in forelimbs and 3 (range 2–4) in hindlimbs.
Koenig et al. (2020) [35]	Case-control comparison of cervical spine radiographs from horses with a clinical diagnosis of cervical facet disease with normal horses	Horses diagnosed with APJ pathology at the Ontario Veterinary College between 2009–2015 (n = 102) and met inclusion criteria (n = 30). Inclusion criteria were (1) clinical signs of neck pain/stiffness, reluctance to collect when ridden, intermittent stumbling, or forelimb lameness, (2) APJs were injected with corticosteroids to allow for follow-up data, and (3) no evidence of CVSM or bone pathology. Cohort-matched control group of 30 clinically normal horses. Mean age for both groups was 10.2 (range 5–19) yrs, with mares (n = 32, 53.3%) and geldings (n = 28, 46.7%). Most prevalent breed was WB (n = 20, 70%).	Retrospective case-control, cohort-matched study	Lateral radiographs	Significant difference in grade of enlargement of the APJs at C5-C6 and C6-C7 between treatment and control horses. Although, 29/30 clinically healthy horses had low levels of APJ enlargement. Clinical signs within the treatment group were neck muscle atrophy (86%), neck stiffness (67%), forelimb lameness (27%), stumbling (20%), and hindlimb lameness (20%).
Lindgren et al. (2021) [36]	Computed tomography and myelography of the equine cervical spine: 180 cases (2013–2018)	Clinical and radiographical records of all horses presented to the Evidensia Equine Specialist Hospital for CT examination of the cervical spinal column from June 2013 to February 2018 were obtained (n = 180). Breeds were WB (n = 143, 79.4%), pony breed (n = 16, 8.9%), Icelandic horse (n = 9, 5%), Standardbred (n = 5, 2.8%), TB (n = 5, 2.8%), and Quarter horse/Paint (n = 2, 1.1%). Mix of geldings (n = 97, 53.9%), stallions/colts (n = 26, 14.4%), and mares/fillies (n = 57, 31.7%). Mean age was 7.1 yrs (range 20 d to 21 yrs).	Retrospective observational case study	CT examination with or without CT myelography	A high proportion (97.8%) exhibited disorder(s) of the cervical spine, including osteoarthritis of the APJs (83.3%), CVSM (85%), and/or ECCMV (15%). 90% had abnormalities caudal to C5. Retrospective clinical signs for the entire group included neurological deficits (52.8%), abnormal neck posture (32.8%), poor performance (31.7%), pain or swelling of the neck (26.7%), and/or forelimb lameness (17.2%).

(*continued on next page*)

Table 2 (*continued*)

Study	Title	Subjects	Study Design	Diagnostic Methodology	Results (Relating to Clinical Signs)
May-Davis (2017) [23]	Congenital malformations of the first sternal rib	Gross post-mortem examinations were collected from 151 horses that either died from natural causes or were euthanised for reasons unrelated to this study. Age range was 0 (stillborn) to 30 yrs, with mixed breeding (TB, TB derivative, purpose bred, and nondescript breeding). Controls were one gelded TB, one female TB, and one gelded Australian Stock Horse.	Observational case series	Post-mortem dissection	6/151 (12%) horses had ECCMV. All were TBs (6/60, 10% of Thoroughbred subjects). Mean age was 11 yrs, included two females and four males. Based on clinical history, ECCMV horses exhibited signs of proprioceptive dysfunction (n = 3), ataxia (n = 3), stumbling (n = 2), lameness (n = 2), forelimb abduction in motion (n = 3) and/or a base-wide forelimb stance (n = 2).
May-Davis & Walker (2015) [24]	Variations and implications of the gross morphology in the *Longus colli* muscle in Thoroughbred and Thoroughbred derivative horses presenting with a congenital malformation of the sixth and seventh cervical vertebrae	Nine horses were included, either TB (n = 7) or TB derivative (n = 2). Excluding one stillborn, the remaining mature horses (n-8) displayed signs of ECCMV premortem. Following death from unknown causes or euthanasia for reasons unrelated to this study, the nine horses underwent post-mortem investigation. The age range was 0 (stillborn) to 23 yrs, with mixed gender.	Observational case series	Post-mortem dissection	All dissected horses (n = 9) had ECCMV confirmed. Frequent clinical signs were base-wide forelimb stance (only seen in bilateral absences), stumbling (6/8), proprioceptive dysfunction (6/8), and difficulty lifting limbs (7/8). Novel observations were unimpeded falls in the paddock resulting in injuries and self-mutilation.
Nollet et al. (2002) [37]	The use of magnetic motor evoked potentials in horses with cervical spinal cord disease	Horses referred to Department of Large Animal Internal Medicine with evidence of clinical signs associated with CVSM or cervical trauma (n = 12). Age range was 1–4 yrs. 6 stallions, 1 gelding, 5 mares. Breeds were Belgian Warmbloods (n = 5), trotters (n = 2), Oldenburger (n = 1), French saddle horse (n = 10), and Haflinger (n = 1). Control horses without clinical signs used for transcranial magnetic stimulation (n = 12).	Case control study	Radiographs, magnetic motor evoked potentials	Radiographic examination revealed cervical abnormalities in 5/11 horses. 2/5 had abnormalities only cranial to C5 or traumatic injury. The remaining 3 horses had anatomical changes to the caudal part of C2-C5 (n = 2), osteochondral fragments at C5-C7 (n = 1) and/or CVSM at C5-C6. Clinical assessment of these 3 horses were severe ataxia in all limbs, ataxia and weakness in all limbs, and severe ataxia and difficulties in keeping upright.
Pezzanite et al. (2021) [38]	Outcomes after cervical vertebral interbody fusion using an interbody fusion device and polyaxial pedicle screw and rod construct in 10 horses (2015–2019)	Retrospective data was retrieved of ten horses undergoing cervical vertebral fusion at Colorado State University between 2015 and 2019. Diagnosis of CVSM was made based on clinical findings and diagnostic imaging. Breeds were WB (n = 2), Tennessee Walker (n = 2), Arabian (n = 2), and Quarter horse (n = 4). Median age was 24 (range 12–168) mo. Two mares, four geldings, four stallions.	Retrospective case series	Radiographs and CT myelography in seven cases	All horses retrospectively diagnosed with CVSM were graded on ataxia according to the Mayhew scale. Median grade 2/5 (range 1–3).
Prange et al. (2012) [10]	Cervical vertebral canal endoscopy in a horse with cervical vertebral stenotic myelopathy	530 kg 3-yr-old Thoroughbred gelding.	Case study	Radiographs, cervical vertebral canal endoscopy, myelography, histology	Owner noted ‘reduced engagement of hindlimbs’ after commencement of race training. Symmetric ataxia and paresis in forelimbs (Grade 2/5) and hindlimbs (Grade 3/5). Varying degrees of APJ osteoarthritis C4-C7. CVSM C6-C7. Myelographic diagnosis of CVSM at C5-C6 but was refuted by histopathological examination of the cervical spinal cord.
Rijckaert et al. (2019) [39]	Determination of magnetic motor evoked potential latency time cutoff values for detection of spinal cord dysfunction in horses	17 ataxic horses presented to the faculty of Veterinary Medicine at Ghent University (Belgium) between 2008 and 2017. Median age was 4 (range 0.5–20) yrs, with 8 stallions, 4 mares, and 5 geldings. All ataxic horses had normal mentation, no cranial nerve deficits, and blindfolding did not trigger a head tilt. All except one horse (only showing ataxia in hind limbs) showed ataxia in both thoracic and pelvic limbs. Five control horses with no abnormalities detected during neurological examination were included. Median age was 7 (range 5–19) yrs, with 2 mares and 3 geldings.	Case control study	Radiographs, myelograms, and histology	No control horses had abnormalities of the cervical neck that were evident radiographically or histologically. Mean grade of ataxia in ataxic horses (n = 17) was 3.6/5 (ranging 1–5). 13 showed evidence of CVSM either by lateral cervical radiographs (n = 7), additional radiographs or myelograms (n = 6). Of the remaining four ataxic horses, the following findings arose: severe malformation at T8-T9 (n = 1), mild degenerative and inflammatory lesions (n = 1), moderate mononuclear inflammation (n = 1), and moderate degenerative lesions at the level of the spinal cord.

Abbreviations: APJ, articular process joint; CVSM, cervical vertebral stenotic myelopathy; ECCMV, equine caudal cervical morphological variation.

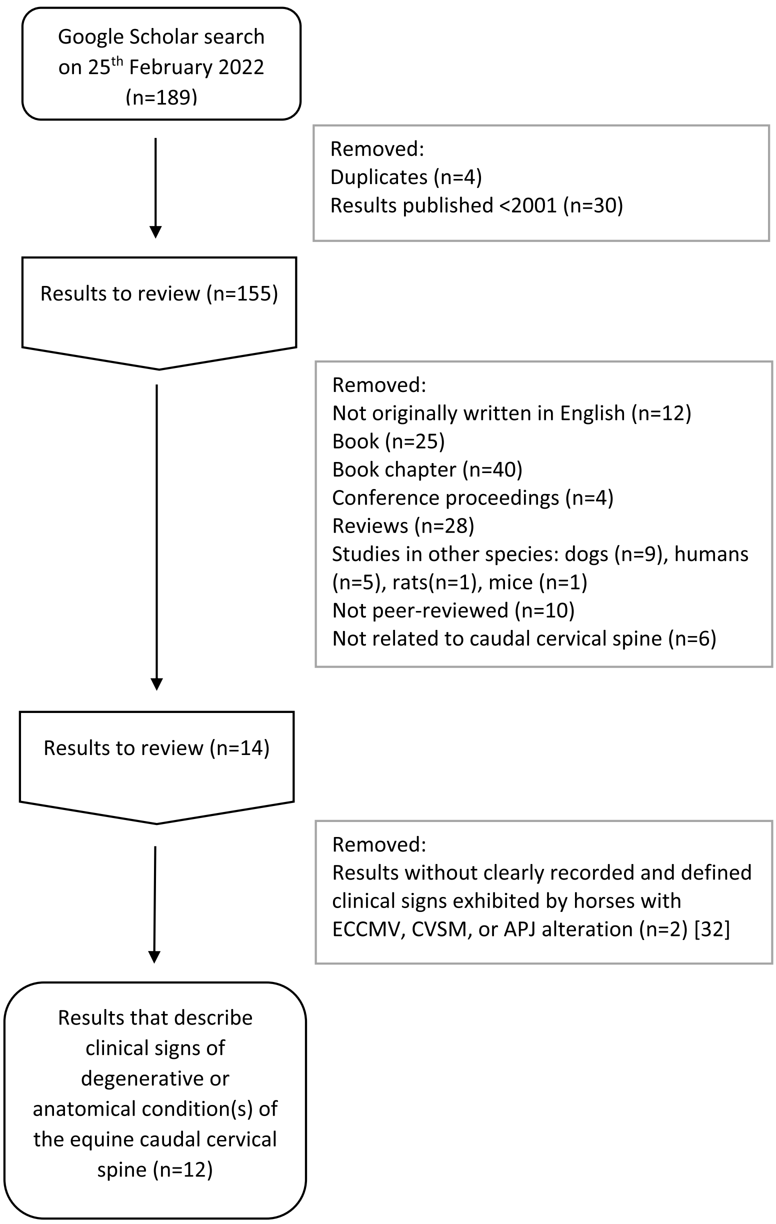

Fig. 4. Flow diagram illustrating application of inclusion criteria resulting in eligible studies (n = 12) from Google Scholar search "equ OR horse AND caudal cervical AND clinical; anatomical variation; malformation; vertebrae; wobbler." [32]

to 2001 (n = 30), leaving a group of results to be more closely reviewed (n = 155). A large proportion (n = 143, 77%) of results were excluded for failing to meet the remaining inclusion criteria listed in Table 1. Many excluded results were book chapters (n = 40), reviews (n = 28), or books (n = 25). Though some results written in other languages had an English version available, these were not included to avoid misinterpretation and variation between languages. This process resulted in a small group (n = 12, 0.05%) of eligible studies for inclusion in this review.

3.1. Study Characteristics

Characteristics of the included studies are displayed in Table 2. Study designs were mainly observational (n = 4) and retrospective (n = 5). The aims of some studies were not directly linked to association of clinical signs with conditions of the caudal neck and some of the results displayed are a result of supplementary information.

A variety of diagnostic methodologies were utilised throughout the included studies. This is likely due to differing presentations of the included caudal cervical disorders and difficulty of effective diagnostic imaging of this region. Combinations of diagnostic imaging methods were often used and included radiographs (n = 9), myelography (n = 4), CT (n = 1), and/or MRI (n = 2). Post-mortem investigation included histology (n = 2) and dissection (n = 2).

3.2. Risk of Bias Assessment

RoB was assessed (Table 3) using criteria adapted from the STROBE checklist created by von Elm et al. (2007) [30], which was initially designed for strengthening evidence of observational studies. As most of the studies included in this review were retrospective and observational, most criteria were able to be applied. Five included studies [10,23,24,37,38] did not apply statistical analytical methods.

Table 3
Risk of bias assessment for included studies.

	Beccati et al. (2020)	Down & Henson (2009)	Janes et al. (2014)	Janes et al. (2015)	Koenig et al. (2020)	Lindgren et al. (2021)	May-Davis (2017)	May-Davis & Walker (2015)	Nollet et al. (2002)	Pezzanite et al. (2021)	Prange et al. (2012)	Rijckaert et al. (2019)
Includes eligibility criteria of case and control[a]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes – no control	No	Yes	NA	Yes
Addresses potential sources of bias[a]	Yes	Yes	No	No	Yes	Yes	No	No	No	Yes	Yes	Yes
Reports numbers of individuals at each stage of the study[a]	Yes	No	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	NA	Yes
Describes characteristics of study participants[a]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Blinding	Yes	No	No	No	Yes	No	No	No	No	Yes	No	Yes
Describes how outcomes were assessed	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Explanation of statistical analysis[a]	Yes	Yes	Yes	Yes	Yes	Yes	NA	NA	NA	NA	NA	Yes

Abbreviation: NA, non-applicable.
[a] Included in STROBE checklist.

3.3. Thematic Analysis

Qualitative data software NVivo was used to determine the frequency of themes mentioned in the 'Results' section of each included study. As Prange et al [10] was a case study, the section analysed was titled 'Case details.' While this will not accurately reflect the results of the included studies, visual representation of thematic coverage where authors discuss their results indicate their main findings of interest. Application of thematic analysis to the results of this review may also assist in forming association between caudal cervical disorder types, locations, and their clinical signs according to in which study they are discussed. Figs. 5, 6, and 7 show occurrence of clinical signs, condition type, and condition location, respectively, in the results of each included study.

ECCMV was associated with neck pain, ataxia, proprioceptive dysfunction, forelimb or hindlimb lameness, and a base-wide forelimb stance [14,23,24]. CVSM was associated with ataxia and neurological deficits of the fore and hindlimbs [10,33,37,38]. Arthropathy of the APJs was associated with neck pain, ataxia, neck muscle atrophy, lameness of the fore and hind limbs, and stumbling [10,14]. Lindgren et al [36] identified neurological deficits, abnormal neck posture, poor performance, neck pain, and/or forelimb lameness as clinical signs in horses affected by ECCMV, APJ alteration, and/or CVSM.

Ataxia was the most mentioned clinical sign among all studies, followed by neck pain/stiffness, stumbling, and forelimb lameness. Pathology or variation occurred at different locations of the caudal cervical spine, however this was not described in some papers [35,39]. APJ alteration and CVSM was seen at C5-C6. Angulation of C5-C6 was associated with anatomical variation at C6-C7 [8]. Pathology at C6-C7 included ECCMV or arthropathy of the APJs. As described by May-Davis [23] and May-Davis and Walker [24], ECCMV cases exhibited uni- or bi-lateral absence of the CVT of C6 with or without uni- or bi-lateral transposition onto the ventral surface of C7. Anatomical variation isolated to C6 was identified in three studies [14,23,24]. However, Beccati et al [14] did not record potential variation of C7 that has shown to be associated with variations in C6, so some cases may have affected both C6 and C7.

4. Discussion

The majority of twelve peer-reviewed, primary research studies included in this review found significant associations with caudal neck conditions and clinical signs, allowing identification of which clinical signs are most often associated with ECCMV, APJ alteration, and/or CVSM.

Ataxia was the most common clinical sign, which related to all three caudal cervical conditions considered in this review [3,10,14,37,38]. Most included studies utilised the Mayhew grading scale [40] to measure ataxia. Use of a standardised grading scale for variable clinical signs such as ataxia may reduce subjectivity to reflect severity more accurately. Mayhew et al [40] described the following grades: 0, deficit not detected; 1, deficit just detected at a normal gait or posture; 2, deficit easily detected and exaggerated by backing, turning, swaying, loin pressure, or neck extension; 3, deficit very prominent at normal gait with tendency to buckle or fall with backing, turning, swaying, loin pressure, or neck extension; and 4, stumbling, tripping, or falling spontaneously at normal gaits, or more severe deficits. This appeared to be an effective method for assessing presence and severity of ataxia.

Due to the observational nature and varying designs of some included studies, quantitative evaluation was unable to be effectively applied in this review. Thematic analysis using qualitative analytical software NVivo 12 aided in identifying relationships between caudal neck pathology location, type, and clinical signs. Beccati et al [14] referred to ECCMV and/or APJ arthropathy at C5-C6, C6,

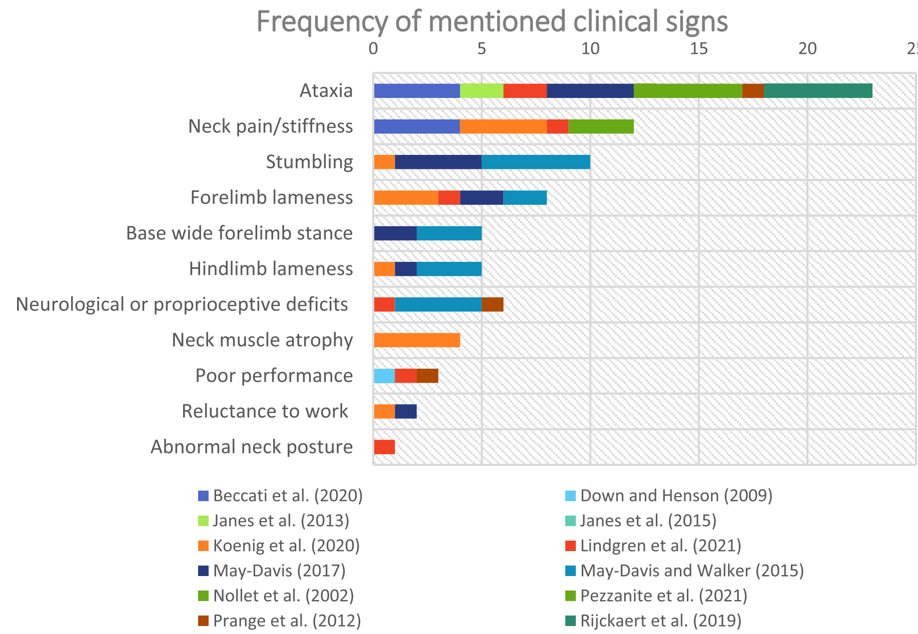

Fig. 5. Number of mentions of clinical signs in the results of included studies.

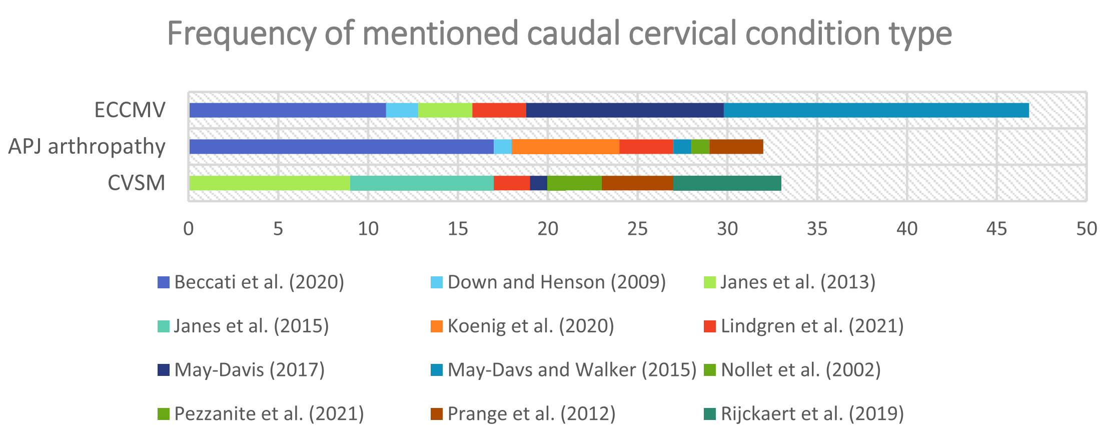

Fig. 6. Number of mentions of caudal cervical condition type in the results of included studies.

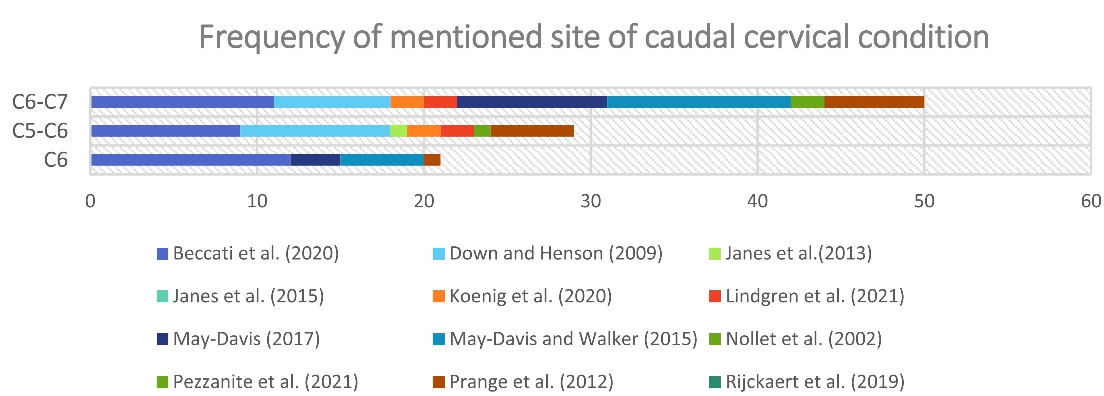

Fig. 7. Number of mentions of caudal cervical condition sites in the results of included studies.

or C6-C7 primarily associated with ataxia and neck pain/stiffness. This is likely a reflection of the study design, which grouped horses into those with neck pain (Group C), those with ataxia (Group A), and healthy horses (Group H). Group C also included horses showing inability or difficulties eating from the ground, neck fixing, and forelimb lameness. Due to these generalisations, other clinical signs that may have been present were likely overlooked. Nonetheless, it provided confirmation of other studies that have suggested ataxia and neck pain to be associated with ECCMV and/or alteration of APJs [16,23,33,36,41].

Conditions of the equine caudal neck may occur concurrently and have been suggested to be related [8,14,15,20,22]. Gough et al [20] identified CVSM and remodelling of the APJs in 61% and 98% respectively in the same group of 51 horses. ECCMV has been linked to CVSM by causing dorsoventral narrowing of the vertebral canal [18]. Alterations in attachment points of *Longus colli* muscle is noted in several included studies [14,23,24] and appears to occur alongside ECCMV [36].

The caudal cervical curvature in the neck requires significant stabilization by the perivertebral musculature, including *L. colli* [42]. All three layers of this muscle (superficial, medial, and deep), usually attach to the CVT of C6 [8]. Absence, alteration, or transposition of the C6 CVT, will result in abnormal attachment of *L. colli*, in most cases to the ventral surface of C7. This causes asymmetrical loading and impairment of the muscle's intersegmental stabilizing role [24]. It is likely that dysfunction of *L. colli* may contribute to cervical pain, loss of stability, proprioceptive deficits, and compromised neuromotor control in horses [42].

Some previous studies have failed to find associations between caudal neck conditions and clinical signs [43], including one study included in this review [3]. Down and Henson [3] investigated potential associations between grade of caudal cervical APJ enlargement with the breed, age, sex, usage of the horse, and clinical signs. The clinical signs that were retrospectively identified in the treatment group included ataxia, neck stiffness, episodes of neck fixing, and forelimb lameness. In the group of 122 horses that either had no clinical signs or had clinical signs referable to pathology caudal to C5. However, any horses that exhibited clinical signs referable to vertebrae cranial to C5 were excluded. A novel grading system was used to assess degree of enlargement with eight levels. An exact Fisher's test showed no association between presence of clinical signs and grade of APJ enlargement. However, it is unclear if there was a significant difference between horses with presence of any enlargement and clinical signs. There was also no indication of number of horses at each grade of APJ enlargement.

There is significant variation in clinical signs between horses with conditions of the caudal cervical spine. While some owner complaints are associated with subtle declines in performance and inability to meet athletic demands, other horses may exhibit dangerous behavior [44]. A recent paper [45] conducted various diagnostic procedures including gross and histopathologic evaluations of 14 horses that were euthanised due to consistent demonstration of dangerous behavior. Recurring owner complaints included stumbling, rearing, aggressive head tossing, bucking, inability to lower head, and aggressive behavior. All horses were found to have lesions of the nervous system ($n = 14$) and all horses that underwent gross pathologic evaluation ($n = 13$) showed evidence of pathology in the caudal cervical region. Some ECCMV horses in May-Davis [23] were subjected to euthanasia due to falling during racing or transport. Clinical signs highlighted in this review that appear to be associated with caudal cervical conditions have potential to compromise safety of both horse and rider, such as ataxia, stumbling, and proprioceptive deficits. However, it is important to recognise that presence of caudal neck abnormalities in horses does not definitively render a horse unrideable or unusable. Horse wastage due to diagnosis of a caudal neck disorder may be reduced by a deeper understanding of the aetiology, implications, and management of specific conditions and at an individual level.

Large muscle mass and complexity of surrounding structures impedes clarity of diagnostic imaging of the equine neck [22,46,47]. This presents challenges in radiographic positioning and interpretation [3], leading to a potentially inaccurate prevalence of caudal cervical pathologies in live horses assessed in studies and daily veterinary practice [9,16]. Assessment of the APJs can be achieved by lateral oblique radiographic images [46], computed tomography (CT) [48], and/or CT myelography [36]. ECCMV may be detected with computed or digital radiography [9,14]. Intervertebral sagittal diameter measurements may be achieved from survey radiographs [15,18,22], CT [16] and/or CT myelography [20], but require correct orientation and techniques [9,20]. Magnetic resonance imaging (MRI) has been utilised to achieve sagittal, transverse, and dorsal plane imaging of the neck [33,34]. Cone beam computed tomography (CBCT) is an emerging technique that offers promising value for equine cervical spine diagnostic imaging [49,50]. Prange et al [10] suggests the use of cervical vertebral canal endoscopy to detect vertebral canal compression in horses, however its value remains to be demonstrated in a larger group. Other researchers acknowledge the importance of further investigation into associations between diagnostic findings and clinical presentations of caudal neck conditions in the horse to determine a more accurate clinical plan and prognosis [11,16].

Difficulties of diagnostic investigation of the equine caudal neck ultimately creates a limitation of this review. False negative and false positives of CVSM were identified by Janes et al [33] by undertaking antemortem radiographs and post-mortem investigation. Incorrect diagnosis of caudal neck conditions may have contributed to the variable findings throughout previous literature and has potential to cause unnecessary horse wastage and compromise the safety of horses and riders. Post-mortem dissections undertaken in May-Davis [23], and May-Davis and Walker [24] eliminated risk of misinterpretation of diagnostic imaging. Post-mortem investigation may be required to determine accuracy of diagnostic imaging techniques in order to establish reliable antemortem diagnostic methodologies and ultimately decrease horse wastage in the future.

The majority of studies included in this review were conducted retrospectively [2,14,35,36,38]. Therefore, horses may not have been subjected to a full clinical examination to identify potential clinical signs, which is a limitation for this review. In one study, retrospective CT and clinical assessments were used to identify associations in horses with caudal cervical pathology and presence of clinical signs [36]. While this was beneficial in validating previous research and investigating clinical indicators associated with caudal cervical pathology, it did not specify which of these were associated with different types of pathology. Future research should utilise a standardised clinical examination to identify clinical signs recognised in this review.

The language referring to equine caudal cervical pathology in the literature lacks consistency. Anatomical variation of C6 and/or C7 is referred to in literature as ECCMV [9], congenital malformation [8,23,24], morphologic or anatomical variation [11,15,16], or abnormal ventral lamina of C6 (AVL-C6) [14]. The term cervical vertebral malformation (CVM) is also used, however the descriptions of this abbreviation are not consistent with that of ECCMV. Hoffman and Clark [51] define CVM as spinal cord compression, while Nollet et al [37] use CVM to describe radiographic representation of caudoproximal enlargement of C2-C7 vertebral bodies. Narrowing of the spinal canal with potential for spinal cord compression is referred to as cervical stenotic myelopathy (CSM) [33], cervical vertebral compressive myelopathy (CVCM) [52], cervical vertebral stenotic myelopathy (CVSM) [41], or Wobbler's syndrome [17]. While it is acknowledged that CVSM may be associated with ECCMV [33], some studies have referred to these distinct conditions interchangeably [41,51 – 53]. This will likely cause confusion among researchers and practitioners in distinguishing the varying pathology and clinical implications of caudal cervical disorders. Establishing standardised descriptors and language regarding ECCMV, CVSM, and arthropathy of the APJs may allow more reliable associations to be drawn between specific caudal cervical conditions and clinical signs.

There were some further limitations in conducting this review. There was a potential omission of recent research by using only one database. Some relevant papers [15,20,21] were not returned in the Google Scholar search despite the title and/or abstract containing search keywords. Non-peer-reviewed studies and student papers were not included in this review, which may have caused oversight of significant research. Some included studies in this review appeared to use the same group of horses [23,24,33,34]. While each paper has distinct aims and are valuable contributions to the investigation of caudal neck conditions, it may have caused bias in the resulting association of clinical signs. Only one reviewer conducted this systematic review under the guidance of two independent academics. The strength of evidence may have been strengthened by multiple reviewers. The majority of the studies included in this review were observational retrospective studies, creating limitations for accurate assessment of clinical findings and their relationship with types of caudal neck conditions. While all included studies contained information regarding associations of clinical signs to caudal cervical disease, some were conducted for aims not relating to the relationship between pathology and clinical signs [10,33,36 – 38]. Therefore, some results included this study were supporting or supplementary information. There is potential for misinterpretation or lack of thorough experimental design of the results included in this review, which further calls for research focused on clinical signs associated with caudal cervical pathologies.

5. Conclusions

Conditions of the caudal equine neck have been increasingly investigated in recent years, but confusion between relevant terminologies may have influenced the reporting of findings. A systematic review of peer-reviewed, recent literature was conducted to identify associations with caudal cervical conditions and clinical signs for application to equine practice. Ataxia and neck pain were the most prevalent overall indicators associated with anatomical and/or degenerative conditions in the caudal neck. ECCMV was associated with neck pain, ataxia, proprioceptive dysfunction, forelimb or hindlimb lameness, and a base-wide forelimb stance; CVSM was associated with ataxia and neurological deficits of the fore and hindlimbs; and arthropathy of the APJs was associated with neck pain, ataxia, neck muscle atrophy, lameness of the fore and hind limbs, and stumbling. This review highlights the need to further primary research that utilises standardised clinical examinations as opposed to retrospective investigation. Identification of clinical signs associated with these conditions will improve awareness and detection ability in equine practice to ultimately promote welfare and safety of domesticated horses and their riders and handlers.

References

[1] Bainbridge D. The normal anatomy of the neck. In: Henson FMD, editor. Equine neck and back pathology: diagnosis and treatment. Hoboken: Wiley; 2018. p. 1–8.
[2] Zsoldos RR, Licka TF. The equine neck and its function during movement and locomotion. Zoology 2015;118:364–76.
[3] Down SS, Henson FMD. Radiographic retrospective study of the caudal cervical articular process joints in the horse. Equine Vet J 2009;41:518–24.
[4] Getty R. Equine osteology. In: Sisson S, Grossman J, Getty R, editors. Sisson and Grossman's the anatomy of the domestic animals. Philadelphia: Saunders; 1975. p. 255–62.
[5] Whitwell KE, Dyson SJ. Interpreting radiographs 8: Equine cervical vertebrae. Equine Vet J 1987;19:8–14.
[6] Dyson SJ. The cervical spine and soft tissues of the neck. In: Dyson SJ, Ross MW, editors. Diagnosis and management of lameness in the horse. St Louis: Elsevier; 2011. p. 606–16.
[7] Dimock AN, Puchalski SM. Cervical radiology. Equine Vet Educ 2010;22:83–7.
[8] May-Davis S. The occurrence of a congenital malformation in the sixth and seventh cervical vertebrae predominantly observed in Thoroughbred horses. J Equine Vet Sci 2014;34:1313–17.
[9] Gee C, Small A, Shorter K, Brown WY. A radiographic technique for assessment of morphologic variations of the equine caudal cervical spine. Anim 2020;10:667.
[10] Prange T, Carr EA, Stick JA, Garcia-Pereira FL, Patterson JS, Derksen FJ. Cervical vertebral canal endoscopy in a horse with cervical vertebral stenotic myelopathy. Equine Vet J 2012;44:116–19.
[11] Spoormakers TJP, Veraa S, Graat EAM, PRv Weeren, Brommer H. A comparative study of breed differences in the anatomical configuration of the equine vertebral column. J Anat 2021;239:829–38.
[12] Santinelli I, Beccati F, Arcelli R, Pepe M. Anatomical variation of the spinous and transverse processes in the caudal cervical vertebrae and the first thoracic vertebra in horses. Equine Vet J 2016;48:45–9.
[13] Gorton B. Abnormal cervical vertebra of horse. J Anat 1923;57:380–1.
[14] Beccati F, Pepe M, Santinelli I, Gialletti R, Di Meo A, Romero JM. Radiographic findings and anatomical variations of the caudal cervical area in horses with neck pain and ataxia: case–control study on 116 horses. Vet Rec 2020;187:e79.
[15] DeRouen A, Spriet M, Aleman M. Prevalence of anatomical variation of the sixth cervical vertebra and association with vertebral canal stenosis and articular process osteoarthritis in the horse. Vet Radiol & Ultrasound 2016;57:253–8.
[16] Veraa S, Bergmann W, van den Belt AJ, Wijnberg I, Back W. Ex vivo computed tomographic evaluation of morphology variations in equine cervical vertebrae. Vet Radiol & Ultrasound 2016;57:482–8.
[17] Nout YS, Reed SM. Cervical vertebral stenotic myelopathy. Equine Vet Educ 2003;15:212–23.
[18] Van Biervliet J. An evidence-based approach to clinical questions in the practice of equine neurology. Vet Clin N Am: Equine Pract 2007;23:317–28.
[19] Powers BE, Stashak TS, Nixon AJ, Yovich JV, Norrdin RW. Pathology of the vertebral column of horses with cervical static stenosis. Vet Pathol 1986;23:392–9.
[20] Gough SL, Anderson JDC, Dixon JJ. Computed tomographic cervical myelography in horses: technique and findings in 51 clinical cases. J Vet Intern Med 2020;34:2142–51.
[21] Szklarz M, Skalec A, Kirstein K, Janeczek M, Kasparek M, Kasparek A, et al. Management of equine ataxia caused by cervical vertebral stenotic myelopathy: a European perspective 2010-2015. Equine Vet Educ 2017;30:370-76.
[22] Hahn CN, Handel I, Green SL, Bronsvoort MB, Mayhew IG. Assessment of the utility of using intra- and intervertebral minimum sagittal diameter ratios in the diagnosis of cervical vertebral malformation in horses. Vet Radiol & Ultrasound 2008;49:1–6.
[23] May-Davis S. Congenital malformations of the first sternal rib. J Equine Vet Sci 2017;49:92–100.
[24] May-Davis S, Walker C. Variations and implications of the gross morphology in the longus colli muscle in the thoroughbred and thoroughbred derivative horses presenting with a congenital malformation of the sixth and seventh cervical vertebrae. J Equine Vet Sci 2015;35:560–8.
[25] Oswald J, Love S, Parkin TDH, Hughes KJ. Prevalence of cervical vertebral stenotic myelopathy in a population of thoroughbred horses. Vet Rec 2010;166:82–3.
[26] Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffman TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. System Rev 2021;372:n71.
[27] Smith V, Devane D, Begley CM, Clarke M. Methodology in conducting a systematic review of systematic reviews of healthcare interventions. BMC Med Res Methodol 2011;11:15.
[28] Lamb CR, Adams CA. Acceptance rates for manuscripts submitted to veterinary peer-reviewed journals in 2012. Equine Vet J 2014;47:736–40.
[29] Snedeker KG, Campbell M, Totton SC, Guthrie A, Sargeant JM. Comparison of outcomes and other variables between conference abstracts and subsequent peer-reviewed papers involving pre-harvest or abattoir-level interventions against foodborne pathogens. Prev Vet Med 2010;97:67–76.
[30] Von Elm E, Altman DG, Egger M, Pocock SJ, Gøtzsche PC, Vandenbroucke JP. The strengthening the reporting of observational studies in epidemiology (STROBE) statement. Epidemiology 2007;18:800–4.
[31] Liberati A, Altman DG, Tetzlaff J, Mulrow C, Gøtzsche PC, Ioannidis JPA, et al. The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: Explanation and elaboration. Annals Intern Med 2009;151:e1000100.
[32] Bergmann W, Bergknut PN, Veraa S, Gröne A, Vernooij JCM, Wijnberg ID, et al. Intervertebral disc degeneration in warmblood horses: Morphology, grading, and distribution of lesions. Vet Pathol 2018;55:442–52.
[33] Janes JG, Garrett KS, McQuerry KJ, Pease AP, Williams NP, Reed SM, et al. Comparison of magnetic resonance imaging with standing cervical radiographs for evaluation of vertebral canal stenosis in equine cervical stenotic myelopathy. Equine Vet J 2014;46:681–6.
[34] Janes JG, Garrett KS, McQuerry KJ, Waddell S, Voor MJ, Reed SM, et al. Cervical vertebral lesions in equine stenotic myelopathy. Vet Pathol 2015;52:919–27.
[35] Koenig JB, Westlund A, Nykamp S, Kenney DG, Melville L, Cribb N, et al. Case–control comparison of cervical spine radiographs from horses with a clinical diagnosis of cervical facet disease with normal horses. J Equine Vet Sci 2020;92:103176.
[36] Lindgren CM, Wright L, Kristofferson M, Puchalski SM. Computed tomography and myelography of the equine cervical spine: 180 cases (2013–2018). Equine Vet Educ 2020;33:475–83.
[37] Nollet H, Deprez P, Ham L, Verschooten F, Vanderstraeten G. The use of magnetic motor evoked potentials in horses with cervical spinal cord disease. Equine Vet J 2002;34:156–63.
[38] Pezzanite LM, Easley JT, Bayless R, Aldrich E, Nelson BB, Seim III HB, et al. Outcomes after cervical vertebral interbody fusion using an interbody fusion device and polyaxial pedicle screw and rod construct in 10 horses (2015-2019). Equine Vet J 2021;54:1–12.
[39] Rijckaert J, Pardon B, Saey V, Raes E, Van Ham L, Ducatelle R, van Loon G, Deprez P. Determination of magnetic motor evoked potential latency time cut-

off values for detection of spinal cord dysfunction in horses. J Vet Intern Med 2019;33:2312–18.
[40] Mayhew IG, deLahunta A, Whitlock R, Krook L. Spinal cord disease in the horse. Cornell Vet 1978;68:1–207.
[41] Szklarz M, Lipinska A, Slowikowska M, Niedzwiedz A, Marycz K, Janeczek M. Comparison of the clinical and radiographic appearance of the cervical vertebrae with histological and anatomical findings in an eight-month old warmblood stallion suffering from cervical vertebral stenotic myelopathy (CVSM). BMC Vet Res 2019;15:296.
[42] Rombach N, Stubbs NC, Clayton HM. Gross anatomy of the deep perivertebral musculature in horses. Am J Vet Res 2014;75:433–40.
[43] Veraa S, de Graaf K, Wijnberg ID, Back W, Vernooij H, Nielen M, et al. Caudal cervical vertebral morphological variation is not associated with clinical signs in Warmblood horses. Equine Vet J 2019;52:219–24.
[44] Story MR, Haussler KK, Nout-Lomas YS, Aboellail TA, Kawcak CE, Barrett MF, Frisbie DD, McIlwraith CW. Equine cervical pain and dysfunction: pathology, diagnosis and treatment. Animals 2021;11:422.
[45] Story MR, Nout-Lomas YS, Aboellail TA, Selberg KT, Barrett MF, Mcllwraith CW, et al. Dangerous behavior and intractable axial skeletal pain in performance horses: a possible role for ganglioneuritis (14 Cases; 2014–2019). Front Vet Sci 2021;8:734218.
[46] Wither JM, Voute LC, Hammond G, Lischer CJ. Radiographic anatomy of the articular process joints of the caudal cervical vertebrae in the horse on lateral and oblique projections. Equine Vet J 2009;41:895–902.
[47] Hughes KJ, Laidlaw EH, Reed SM, Keen J, Abbott JB, Trevail T, et al. Repeatability and intra- and inter-observer agreement of cervical vertebral sagittal diameter ratios in horses with neurological disease. J Vet Intern Med 2014;28:1860–70.
[48] Claridge HAH, Piercy RJ, Parry A, Weller R. The 3D anatomy of the cervical articular process joints in the horse and their topographical relationship to the spinal cord. Equine Vet J 2010;42:726–31.
[49] Fritsche B, Lorenz I, Busch-Tenter B, Gerlach K. Cone beam-computertomography of the cervical spine in the standing horse – Part 1: findings and clinic. Pferdeheilkunde Equine Med 2020;36:430–7.
[50] Stewart HL, Siewerdsen JH, Nelson BB, Kawcak CE. Use of cone-beam computed tomography for advanced imaging of the equine patient. Equine Vet J 2021;53:872–85.
[51] Hoffman CJ, Clark CK. Prognosis for racing with conservative management of cervical vertebral malformation in Thoroughbreds: 103 cases (2002-2010). J Vet Intern Med 2013;27:317–23.
[52] Levine JM, Adam E, MacKay RJ, Walker MA, Frederick JD, Cohen ND. Confirmed and presumptive cervical vertebral compressive myelopathy in older horses: a retrospective study (1992-2004). J Vet Intern Med 2007;21:812–819.
[53] Anderson JDC. Wobbler surgery: what is the evidence? Equine Vet Educ 2018;32:166–8.