The Veterinary Journal 209 (2016) 133–138

Contents lists available at ScienceDirect

The Veterinary Journal

journal homepage: www.elsevier.com/locate/tvjl

Magnetic resonance imaging-based measures of atlas position: Relationship to canine atlantooccipital overlapping, syringomyelia and clinical signs

S. Cerda-Gonzalez [a,*], K.F. Bibi [b], A.T. Gifford [b], E.L. Mudrak [c], P.V. Scrivani [a]

[a] Department of Clinical Sciences, College of Veterinary Medicine, Cornell University, Ithaca, NY 14853, USA
[b] College of Veterinary Medicine, Cornell University, Ithaca, NY 14853, USA
[c] Statistical Consulting Unit, College of Human Ecology, Cornell University, Ithaca, NY 14853, USA

ARTICLE INFO

Article history:
Accepted 11 January 2016

Keywords:
Brachycephalic
Cavalier
Cervicomedullary
Craniocervical
Neuropathic pain

ABSTRACT

Canine atlantooccipital overlapping (AOO) is characterized by a decreased distance between the dorsal arch of the atlas and the supraoccipital bone. Current diagnostic criteria for this condition are subjective and clinician-dependent; objective criteria are needed to allow a reliable and reproducible diagnosis in clinical and research settings and assess clinical significance. We propose four standardized MRI-based measurements to objectively assess the proximity of the atlas to the foramen magnum. Inclusion criteria for dogs in this study were bodyweight <15 kg, age >5 months, and availability of a complete MRI study performed with the craniocervical junction in extension. Exclusion criteria were space-occupying lesions and poor image quality (i.e. unclear bony margins). Measurements also included blinded determinations of skull type, presence of craniocervical junction anomalies and presence and severity of syringomyelia. Clinical status at the time of imaging was noted.

Measurements were obtained in 271 dogs; these were reproducible and reliable. Findings varied by skull type: dolichocephalic dogs had smaller foramen magnum, whereas brachycephalic dogs had more cranially and dorsally positioned atlas bodies in comparison to the other skull types. Measurements also increased with increases in bodyweight. This study demonstrated a close association between AOO, syringomyelia and clinical signs. Toy and small breed dogs (including Cavalier King Charles spaniels) showed higher than previously reported prevalence of AOO; its occurrence was also associated with lower bodyweights within the study population of <15 kg toy/small breed dogs.

Introduction

Canine atlantooccipital overlapping (AOO) is defined by a diminished distance between the dorsal lamina of the atlas and the supraoccipital bone, with the dorsal lamina of the atlas located either immediately caudal to the foramen magnum or within it (Cerda-Gonzalez et al., 2009a; Dewey et al., 2009; Marino et al., 2012). This condition can cause cerebellar indentation, a reduction in cerebellomedullary cistern size, and may influence medullary position at the cervicomedullary junction (CCJ; Cerda-Gonzalez et al., 2009a; Marino et al., 2012). Prevalence of the condition is highest in small and toy-breed dogs (55%) and lower in Cavalier King Charles spaniels (CKCS; 20%; Marino et al., 2012).

Atlantooccipital overlapping resembles the human condition basilar impression/invagination (BI), in which the atlas and axis are displaced toward or through the foramen magnum, with variable involution of the foramen magnum margins (Chamberlain, 1939; Rao et al., 2002; Tassanawipas et al., 2005; Goel, 2009). Atlantooccipital overlapping and BI are both often seen alongside other CCJ anomalies, such as Chiari-like malformations, medullary elevation/herniation, and atlantoaxial instability (Goel et al., 1998; Rao et al., 2002; Cerda-Gonzalez et al., 2009a; Marino et al., 2012; Driver et al., 2013). In dogs, AOO has also been implicated as a cause of cerebellar indentation (Marino et al., 2012). However, the cause of AOO is unknown and it is unclear whether cranial displacement of the atlas or caudal bulging of the supraoccipital bone causes the overlap to occur.

Both AOO and BI are implicated in the development of neuropathic pain and neurologic dysfunction. Symptomatology has been linked to specific MRI findings in people with BI, such as extension of the dens >5 mm beyond Chamberlain's line (Tassanawipas et al., 2005), or a foramen magnum diameter <25 mm (Cronin et al., 2007). In contrast, the relationship between clinical signs and AOO has not been fully defined in dogs. Affected dogs are described as showing signs of cerebellar and cervical spinal cord dysfunction and head and neck pain (Cerda-Gonzalez et al., 2009a; Dewey et al.,

* Corresponding author. Tel.: +1 607 351 9539.
E-mail address: sc224@cornell.edu (S. Cerda-Gonzalez).

http://dx.doi.org/10.1016/j.tvjl.2016.01.008
1090-0233/

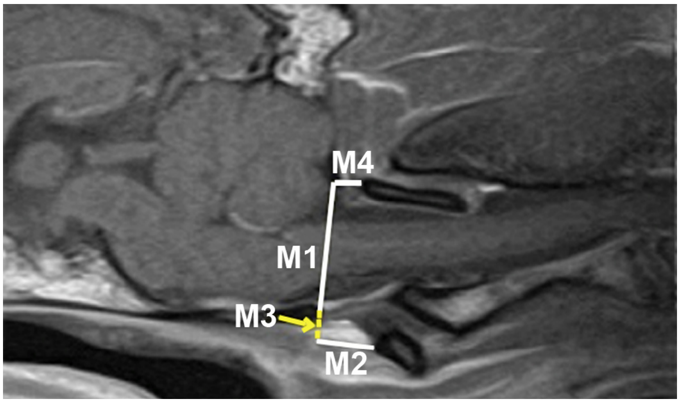

Fig. 1. T1-weighted mid-sagittal post-contrast MRI image illustrating measurements (M) 1 through 4. M1 extends from the ventral margin of the supraoccipital bone to the basioccipital bone's caudal edge (i.e. foramen magnum line). M2 extends perpendicularly from M1, to the cranial-most aspect of the body of the atlas, extending M1 ventrally if needed, to measure M2. M3 extends dorsally, perpendicular to M2, up to the level of the basioccipital bone. M4 extends perpendicularly from L1, to the cranial edge of the lamina of the atlas.

2009). However, these signs are solely linked to subjective diagnostic criteria.

Similarly, whereas a clear link to the development of syringomyelia has been established in humans with BI secondary to changes in blood and cerebrospinal fluid flow, a relationship between AOO and syringomyelia is suspected in dogs but has not yet been demonstrated (Cerda-Gonzalez et al., 2009a; Driver et al., 2013). Objective criteria are needed for evaluating atlas position, to more precisely diagnose AOO and to evaluate its relationship to clinical signs and syringomyelia.

Our study aims were: (1) to describe measurements that objectively assess atlas position in dogs and their relationship to dog characteristics (i.e. signalment, bodyweight, and skull type); (2) to describe the relationship between these and CCJ anomalies such as AOO; and (3) to determine whether the measurements are associated with clinical signs and syringomyelia. We hypothesized that in dogs with subjectively diagnosed AOO, the atlas would be positioned closer to the foramen magnum (i.e. smaller M2, M3, and M4 measurements, Fig. 1), and that this would be associated with clinical signs and syringomyelia.

Materials and methods

Case selection

We queried the medical records database of the Cornell University Hospital for Animals to identify dogs with an MRI study performed between 2008 and 2014, a complete medical record (i.e. signalment, bodyweight, clinical history, neurologic examination), and an age >5 months (i.e. post-vertebral growth plate closure) at imaging. Dogs were excluded if the imaging study did not include the caudal cranial fossa, CCJ, and first two cervical vertebrae, or the imaging study was incomplete. For this investigation, complete studies included T1- and T2-weighted sagittal, and T1- and T2-weighted transverse sequences obtained with the CCJ positioned in extension (i.e. straight), exclusively. Further exclusion criteria included: bodyweight >15 kg, a space-occupying lesion within the caudal fossa or first two cervical vertebrae, infratentorial herniation, and poor image quality (i.e. unclear bony margins). The bodyweight limitation of <15 kg was chosen to focus our evaluation on the population of dogs most affected by CCJ anomalies (i.e. small and toy breed dogs; Cerda-Gonzalez et al., 2009a; Parker et al., 2011; Marino et al., 2012; Freeman et al., 2014).

The following demographic information was acquired from each medical record: age at the time of imaging, breed, sex, and bodyweight. Clinical signs at the time of imaging were also documented. Dogs with histories of scratching of the neck or shoulder, cervical hyperesthesia, or a cervical myelopathy were considered symptomatic for purposes of this study. Grading of clinical signs was impossible due to the retrospective nature of this study.

Image analysis

Magnetic resonance imaging was performed with 0.2 T or 1.5 T MRI units (Esaote, Toshiba Vantage Atlas). Images were reviewed using Picture Archiving and Communication System software (v.1.4.0.1253, Carestream Vue Solutions). Observers were blinded to signalment, clinical signs, diagnosis (including imaging diagnosis), and each other's findings. Measurements were performed by a single observer (KB), who was trained for this study. A second observer evaluated the CCJ for cerebellar herniation, cerebellar indentation, dorsal compressive atlantoaxial bands, and syringomyelia (Lu et al., 2003; Cerda-Gonzalez et al., 2009b). Dogs were diagnosed as having AOO when the cranial-most aspect of the arch of the atlas was within or immediately caudal to the foramen magnum (Cerda-Gonzalez et al., 2009a; Marino et al., 2012). Severity grades were assigned to atlantoaxial band-associated compression and syringomyelia, as described previously (Cerda-Gonzalez et al., 2015a, 2015b). Grades of AOO were assigned as follows: grade 1, atlas immediately caudal to the foramen magnum; grade 2, atlas at the level of the foramen magnum; and grade 3, atlas within the foramen magnum. Dogs were also classified according to skull type as brachycephalic (B), dolichocephalic (D), or mesocephalic (M), according to previously described criteria (Hussein et al., 2012; Schmidt et al., 2014). Magnetic resonance imaging studies that did not include the entire skull were excluded from skull type analyses.

Craniocervical junction measurements

Four linear measurements were performed (Fig. 1) using T1-weighted mid-sagittal MRI images; cortical bone hypointense signal was used as the starting point for each measurement, as described previously (Cronin et al., 2007). Measurement 1 (M1) assessed foramen magnum height, as described previously (Lu et al., 2003; Cerda-Gonzalez et al., 2009b). Measurement 2 (M2) evaluated the shortest perpendicular distance between the foramen magnum and the craniodorsal edge of the body of the atlas. Measurement 3 (M3) evaluated the ventrodorsal position of the body of the atlas, by measuring the perpendicular distance between M2 and the ventral-most aspect of M1 (i.e. dorsocaudal edge of basioccipital bone). Measurement 3 was recorded as positive if the body was dorsal to the basioccipital bone, and negative if it was ventrally located. Measurement 4 (M4) evaluated the perpendicular distance between M1 and the cranial edge of the lamina of the atlas. Measurements were recorded as negative if the lamina was located within the cranial cavity (Fig. 2).

Statistical analysis

Analyses were performed using JMP Pro version 11 (SAS Institute) and SPSS statistics version 22 (IBM). Data analyzed included AOO presence (Yes/No) and severity (grades 0–3); cerebellar indentation (Yes/No); cerebellar herniation (Yes/No); dorsal atlantoaxial band presence (Yes/No) and severity (grades 0–3; Cerda-Gonzalez et al., 2015a); presence of syringomyelia (Yes/No) and severity (grades 0–3; Cerda-Gonzalez et al., 2009b); skull type (brachycephalic, dolichocephalic, or mesocephalic); presence of clinical signs (Yes/No); and measurements 1–4 (continuous). Univariate

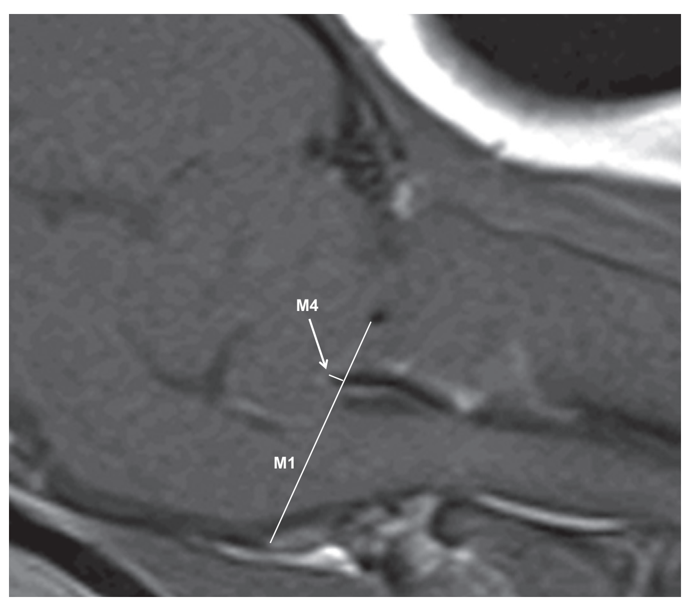

Fig. 2. T1-weighted mid-sagittal MRI image demonstrating measurement 4 (M4). In this case, M4 was recorded as a negative value since the lamina of the atlas is located within the foramen magnum. M1, measurement 1.