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Comparative anatomy and biomechanical properties of atlantoaxial ligaments in equine, bovine and canine cadaver specimens

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Running Title: Anatomy and Biomechanics of atlantoaxial ligaments

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Conflicts of Interest

The authors have no conflicts of interest to report.

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Summary

Objectives

Atlantoaxial instability has been reported in humans, canines, equids and ruminants. The functional role of the atlantoaxial ligaments has only been described rudimentarily in equids and ruminants. The goal of the present cadaveric study is to compare the anatomy between the different species and to comparatively assess the role of the stabilizing ligaments of the atlantoaxial joint under sagittal shear loading in canine, equine and bovine cervical spines.

Methods

Three equine, bovine and canine cadaver specimens were investigated. Biomechanical testing was performed using a purpose built shear-testing device driven by a uniaxial servo hydraulic testing machine[a]. Three cycles in dorsoventral direction with a constant quasi-static velocity of 0.2 mm/s up to a limiting force of 50 N (canine) or 250 N (bovine, equine), respectively, were performed for each specimen tested. Load and linear displacement were measured by the displacement sensor and load cell of the testing system at a sampling rate of 20 Hz. Tests were performed and the ROM (Range of Motion) determined with both intact and transected atlantoaxial ligaments.

Results

Only in the canine specimens ROM significantly increased after transection of the ligaments. The bovine atlantoaxial joint is biomechanically more stable than in equids.

Clinical significance

Species-specific anatomical and biomechanical differences of the atlantoaxial ligaments in canines, equids and bovines were detected. How significant these differences are and how their impact on the pathogenesis of atlantoaxial subluxations and subsequent treatment is, remains open.

Introduction

Atlantoaxial instability is a well-recognised condition of the upper cervical spine in humans and small companion animals with a predisposition in toy breed dogs. Atlantoaxial instability also has been reported in equids and ruminants (1-5). In previously reported bovine cases, mostly the atlantoaxial instability was caused by a congenital malformation of the odontoid process and/or atlanto-occipital fusion (1,2). Only one case of a calf with traumatic atlantoaxial instability associated with an odontoid fracture has been described to date (6).

In horses, atlantoaxial luxation occurs most commonly as a consequence of genetic malformation of the atlantoaxial joint and has been reported predominantly in Arabian breeds (4). Traumatic subluxation or luxation of the atlantoaxial articulation without a fracture of the dens is uncommon and usually observed in younger horses (5).

The functional anatomy of the atlantoaxial ligaments has been investigated in humans and dogs, including the detailed description of which ligaments of the dens provide atlantoaxial joint stability in these species (7). This is not the case in equids and ruminants and the role of the atlantoaxial ligaments has only been basically described in these species (3).

The purpose of this study is to compare the anatomy between the different species and more specifically to comparatively assess the role of the stabilizing ligaments of the atlantoaxial joint under sagittal shear loading in canine, equine and bovine cervical spines. The importance of shear loading forces is explained by continuous tension in the ligaments in order to support the weight of the head in a sagittal plane.

Material and methods

Specimens

Three adult equine (Arabian), bovine (Simmental) and canine (Beagle) cadaver specimens were used. All specimens were examined by CT^{b} to exclude preexisting occipito-atlanto-axial pathology (Figure 1). Subsequently, the craniocervical region was prepared in all specimens as previously described (7). Two out of three specimens in each species were stored at -25°C for biomechanical testing and the third specimen of each species were used for anatomical description and immediately underwent complete anatomical dissection.

Anatomy

Peripheral ligaments include the dorsal atlantoaxial membrane and the dorsal atlantoaxial ligament. In bovines and equids these ligaments are complemented by the ventral atlantoaxial ligament, which connects the ventral tubercle of the atlas to the ventral crista of the axis.

The tectorial membrane covers the floor of the vertebral canal from the body of the axis to the ventral border of the Foramen magnum. The tectorial membrane is present in all the species. In dogs, it is complemented by the apical ligament of the dens which connects the dens axis to the basilar part of the occipital bone and by the paired alar ligaments which run from the lateral borders of the dens to the corresponding occipital condyle. In addition, the transverse ligament of the atlas crosses the canine vertebral canal dorsal to the dens and prevents the latter from protruding towards the spinal cord. The apical ligament of the dens is also present in the bovine, in which the atlantoaxial joint is further secured by the longitudinal ligament of the dens. The *longitudinal* ligament of the dens ends at the inner surface of the ventral arch of the atlas. The longitudinal ligament of the dens is the only ligament being connected to the dens of the axis in the equid (8).(Figure 2)

Mechanical Testing

The atlanto-occipital joints were blocked with two transarticular diverging 1.8 mm positive threaded K-wires in canine, and with two 4.5 mm cortical screws in equine and bovine specimens, respectively. In the canine specimens, the occipital bone and the caudal end of C2 were secured as previously described (7). In the equine and bovine specimens, both ends of the tested specimens were secured with screws crossing specially designed plates to allow mounting of these large preparations in the testing machine.

Biomechanical testing was performed using a purpose built shear-testing device driven by a uniaxial servo hydraulic testing machine[a] (7). This device provided shear loading in a sagittal plane.

The limiting force of 50 N was set for the final test series in canine specimens in a way that the measured response included the full sigmoid-shaped load deformation curve associated with physiologic loading without approaching the loading limit of the ligaments at 107 N (7). For equine and bovine specimens, a limiting force of 250 N was arbitrarily chosen.

Three cycles in a dorsoventral direction with a constant quasi-static velocity of 0.2 mm/s up to a limiting force of 50 N or 250 N, respectively, were performed for each specimen tested. Load and linear displacement were measured by the displacement sensor and load cell of the testing system and collected throughout the tests at a sampling rate of 20 Hz. The 3rd cycle was used for analysis.

Range of motion (ROM) was defined as the total displacement within the load limits.

The test was performed and ROM was determined with all ligaments intact and after transection of all atlantoaxial ligaments. After testing, complete transection of all the ligaments was confirmed by removal of the dorsal arch of the atlas and inspection of the atlantoaxial junction.

Results

ROM considerably increased in canine specimens after transection of the ligaments. This was not observed in bovine and equine specimens in which transection of the odontoid ligaments did not lead to remarkable changes in ROM. The bovine atlantoaxial joint is biomechanically more stable than in equids. (Figure 3)

Discussion

These results highlight not only distinct anatomical differences between the atlantoaxial ligaments of canines, bovines and equids but also show that these result in measurable functional differences. Unlike in canine specimens, transection of the ventral atlantoaxial ligaments did not lead to a significant increase in ROM in equine and bovine specimens. This suggests that only in canine specimens, the ligamentous support structures are crucial for the stabilization of the atlantoaxial joint under shear loading.

This observation is supported by the current literature. Whereas in canines, agenesia or rupture of the atlantoaxial ligaments with an intact odontoid process, has commonly been described as a cause of atlantoaxial instability (9), this is not the case in equids and bovines. Reported cases of atlantoaxial subluxation in these two species were consistently associated with malformation of the atlantooccipital region and/or malformation or fracture of the odontoid process (6). In equids, complete tearing of the ligamentous attachments of the dens and disruption of the atlantoaxial joint capsule are necessary to allow complete luxation of the joint, whereas partial tearing of the ligamentous and capsular support can result in subluxation (3). However, subluxation or luxation of the atlantoaxial articulation without fracture of the dens is very uncommon and usually observed in younger horses with a pre-existing congenital anomaly (5). In a biomechanical experimental study investigating atlantoaxial stabilization methods in a bovine model, instability was also created by resection of the base of the dens without transection of the ventral atlantoaxial ligaments (10). These findings may be explained by the anatomical differences existing between the ligaments but are most likely mainly due to the specific anatomy of the fovea dentis which is much deeper and more developed in equids and ruminants, thus preventing a dorsal dislocation of the dens. This observation might also explain why the dens slips more easily towards ventral resulting in ventral luxation, which is the most frequently recognized form of luxation in equine atlantoaxial joints.

In small companion animals dens fractures commonly result from high velocity hyperflexion of the neck (9). Similarly traumatic hyperflexion or hyperextension of the neck is reported to cause atlantoaxial fractures in horses (3). In calves, cervical trauma leading to atlantoaxial instability is usually attributed to traumatic hyperflexion or hyperextension of the neck by accidents (6). However, the available literature only provides sparse reports on the integrity and the potential role of the atlantoaxial ligaments in cases of observed instability. In these cases, in equids and bovines, fracturing of the odontoid process may be the main cause of instability, leading to a dorsal displacement of the axis. At the same time, the ventral ligamentous atlantoaxial support may remain intact and, in association with the well distinguished conformation of the fovea dentis, explains why the dens axis remains in place ventrally in these species. This is not the case in canines where a dorsal displacement of the dens is frequently observed. As a consequence of these anatomical differences, the cause of spinal cord compression seems to be different in canines compared to equids and bovines with odontoid process fractures.

Some limitations have to be considered when interpreting our results. Firstly, the low number of specimens included. The maximal forces used for the biomechanical testing of the equine and bovine specimens were set arbitrarily, based solely on previous experiences of the authors, and may therefore not be representative of the in-vivo situation. Furthermore, two different sample fixation methods were used; one for the biomechanical testing in large animal cadaver specimens (equine and bovine) and another for the small animal (canine) specimens.

Finally our study documents species-specific anatomical and biomechanical differences of the atlantoaxial ligaments in canines, equids and bovines. How far these differences impact the pathogenesis of subluxation and luxation of the atlantoaxial articulation and its treatment in these species remains to be clarified.

Footnotes

[a] MTS Bionix, MTS, Eden Hill, PA

[b] Philips Brilliance, CT 16-slice, Philips AG Healthcare, Zürich, Switzerland

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Legends

Figure 1: Sagittally reconstructed CT image of the canine (A), bovine (B), and equine (C) occipito-atlanto-axial region.

Figure 2: Anatomy of atlantoaxial ligaments in the canine (A), bovine (B) and equine (C) occipito-atlanto-axial region. All specimens are orientated with head upwards and cervical spine downwards. Alar ligaments (white arrows) and transverse ligament (white dot) are only present in dogs. Apical ligament is present in canids and bovids (black dot). Paired longitudinal ligaments are the main ligaments in bovids and equids (black arrows).

Figure 3: Force–displacement behavior of canine, bovine and equine specimen intact and after transection of the atlantoaxial ligaments. Positive displacement represents motion in dorsal direction.