Effect of Facetectomy on the Three-Dimensional Biomechanical Properties of the Fourth Canine Cervical Functional Spinal Unit: A Cadaveric Study

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Abstract

Objective To study the biomechanical effect of facetectomy in 10 large breed dogs (>24 kg body weight) on the fourth canine cervical functional spinal unit.

Methods Canine cervical spines were freed from all muscles. Spines were mounted on a six-degrees-of-freedom spine testing machine for three-dimensional motion analysis. Data were recorded with an optoelectronic motion analysis system. The range of motion was determined in all three primary motions as well as range of motion of coupled motions on the intact specimen, after unilateral and after bilateral facetectomy. Repeated-measures analysis of variance models were used to assess the changes of the biomechanical properties in the three treatment groups considered.

Results Facetectomy increased range of motion of primary motions in all directions. Axial rotation was significantly influenced by facetectomy. Coupled motion was not influenced by facetectomy except for lateral bending with coupled motion axial rotation. The coupling factor (coupled motion/primary motion) decreased after facetectomy. Symmetry of motion was influenced by facetectomy in flexion–extension and axial rotation, but not in lateral bending.

Keywords ► biomechanics ◄ dogs ◄ facetectomy ◄ cervical

Clinical Significance Facet joints play a significant role in the stability of the cervical spine and act to maintain spatial integrity. Therefore, cervical spinal treatments requiring a facetectomy should be carefully planned and if an excessive increase in range of motion is expected, complications should be anticipated and reduced via spinal stabilization.

Introduction

Facetectomy is a decompressive spinal surgical technique that has been sparsely discussed in the veterinary literature in regard to the lumbar spine, and even less in the cervical spine of dogs.¹–³ Recently this technique has regained attention for relief of foraminal stenosis associated with lumbar-sacral stenosis.⁴ Degenerative changes of the facet joints in the cervical spine are a frequent finding in large breed dogs with osseous associated spondylomyelopathy that can induce lateral spinal cord compression and foraminal stenosis.⁵,⁶ Cervical facetectomy has been described to treat osseous associated spondylomyelopathy as well as lateralized, foraminal intervertebral disc extrusion impinging a
nerve root. Furthermore, arachnoidal and synovial cysts in facet joints as well as menigioma and vertebral arch anomalies could be treated by facetectomy. The more challenging approach through the deep dorsal and dorsolateral cervical paraspinal muscles and the post-surgical decrease in spinal stability are frequent concerns for surgeons, outweighing the advantages and inconvenience of performing cervical facetectomy.

Investigations of the biomechanical effects induced by hemilaminectomy in the canine lumbar vertebral column have been reported. To the authors’ knowledge, there have not been any studies of humans or animals which have analysed biomechanical data after facetectomy in the cervical spine and the effect on stability of such a procedure.

Three-dimensional motion pattern of the intact canine cervical vertebra (C) of the C4–C5 segment, the C2–C4 segment and the C5–C7 segment have recently been described in different studies of large breed dogs. The conclusion was that the biomechanical characteristics of the canine cervical spine differ from those in the human cervical spine. Furthermore, some biomechanical studies have been performed on postoperative biomechanical changes induced by fenestration, ventral slot and cervical stabilization techniques in dogs. According to the results of these studies, the intervertebral disc plays a major role in the stability of the cervical spine. The stabilizing role of the cervical facet joints however has not been investigated so far.

The C4–C5 segment was selected for this study as it is neither the most flexible nor the most rigid part of the cervical spine. Range of motion (ROM) in flexion–extension of the cervical spine slightly decreases from C2–C3 to C6–C7; the ROM of left–right lateral bending progressively increases towards caudal with the highest values for C6–C7.

The goal of our study was to describe the role of the facet joints on the overall movement and to evaluate the effect of unilateral and bilateral facetectomy on the postoperative stability of the C4–C5 motion unit. We tested bilateral facetectomy, which is rarely performed in standard clinical situations, to anticipate stability problems that might occur after an iatrogenically induced fracture of the contralateral joint in case of extensive dorsal exposure of the spinal canal and to investigate if a bilateral facetectomy could be safely considered without further spinal stabilization in dogs with bilateral osteoarthritic changes of the facet joints.

Our hypothesis was that unilateral and bilateral facetectomy would consistently change the three-dimensional motion characteristics of the cervical vertebral motion unit. In particular, we expected that (1) removal of the facet joints would lead to an increased range of the primary motion (PM), whereas the ROM of the coupled motion (CM) would decrease and (2) the most symmetrical motion would occur after bilateral facetectomy.

Materials and Methods

Cervical spines of 10 large breed dogs with a mean body weight of 36.1 kg (standard deviation [SD] of ± 8.21; range: 25–45 kg) and a mean age of 8.16 years (SD of ± 2.57) were included. The dogs had been euthanatized due to illnesses unrelated to this study. Dogs with cervical spinal pathologies were excluded based on clinical signs at presentation, radiographs of the cervical spine and macroscopic assessment of the spine after specimen preparation. The cervical spine region C3–C5 was harvested from each dog. Of these 10 specimens, the right facet joint was first removed and in the other 5 the left facet joint was first removed. One supplementary specimen was used for a pilot study and therefore not included in the statistical analyses. The spines were stripped of their musculature without damaging ligaments and facet joints. The cervical column was wrapped in a cotton towel, soaked in physiological saline solution and stored at −20°C until testing was performed. Twelve hours prior to testing, the spines were thawed at room temperature. The specimens were regularly sprayed with saline during the entire preparation and testing phase.

The vertebral bodies of C6 and C7 were embedded in polymethyl methacrylate (PMMA) cement. Four wood screws were applied in a horizontal direction into the vertebral body of C3 for better fixation of the PMMA block. In the vertebral body of C6, the screws had to be angulated 45° to the spinal long axis to create pillars. The screws were fixed in a way that the specimens were positioned in an upright position. The specimens were then embedded in PMMA.

Flexibility tests were performed in a custom-built six degrees of freedom spine loading simulator (Fig. 1) to apply pure moment loading within the individual three principal testing axes, while the specimen was allowed to move in an unconstrained three-dimensional fashion. A common flexibility test was conducted for each loading direction, which consisted of four consecutive loading cycles in the directions of flexion–extension, left–right lateral bending and left–right axial rotation, respectively. The load was applied by a constant quasi-static angular motion of 0.1°/s up to a moment of 1 Nm. The first two cycles served to precondition the sample while kinematic data were derived from the third cycle, with a fourth loading cycle performed to ensure completeness of the analysed motion. All specimens were tested in the order of flexion–extension, left–right lateral bending and finally in left–right axial rotation.

A six-axis load cell (MC3A, AMTI, Watertown, Massachusetts, United States) at the cranial end of the specimen recorded all the moments and forces acting on the specimen during testing at a sampling rate of 5 Hz. The three-dimensional motion pattern was measured by an active optoelectronic tracking system (Optotrak 3020, Northern Digital, Waterloo, Ontario, Canada; nominal marker resolution 0.1 mm). Two marker plates with four light-emitting diodes each were ventrally attached to the vertebral bodies of C4 and C5.

After testing of the intact specimens, the specimens were randomly assigned to removal of either the left or the right facet joint. The chosen facet joint was removed with a high-power burr (Minos, Linvatec, Laubscher AG, Basel, Switzerland). A second run of tests was performed in the same test settings. In a third run, the tests were performed after the contralateral facet joint had been ground off with the high-speed burr.

Angular motion was calculated out of the raw data from the optical tracking system using Matlab (Matlab 2008,
Mathworks, Massachusetts, United States) and synchronized with the load measurements of the spinal loading. To take into account the fact that all three treatments were performed in the same 10 animals, we included the variable treatment as a ‘within variable’. The dog identification number was used as the ‘subject variable’. Besides, we ran additional ANOVA models, in which we included the weight of the animal and the side as ‘between variables’ to test their effect in association to all variables with treatment. The CM/PM ratio was calculated to enable a comparison with results from a previous study\textsuperscript{11} and to compare intact, unilateral and bilateral facetectomy.

**Results**

**Range of Primary Motion (PM)**

All PM as well as the corresponding CM showed a normal type of hysteresis curve in all three test settings (\textsuperscript{Fig. 2}). Facetectomy increased the ROM of the PM in all directions (\textsuperscript{Fig. 3} and \textsuperscript{Table 1}).

Flexion–extension: Range of motion progressively increased from intact to unilateral to bilateral facetectomy. The repeated measures ANOVA with Bonferroni correction revealed statistical significance (p-value < 0.01) both after unilateral and after bilateral facetectomy. In total, there was an increase in ROM of 19.4\%, whereby the increase from intact to unilateral facetectomy (9.9\%) and the increase from unilateral to bilateral facetectomy (8.6\%) were almost equal (see \textsuperscript{Table 1}).

Lateral bending: Repeated measures ANOVA also revealed that unilateral facetectomy was not significantly different from bilateral facetectomy (increase of only 0.9\%). Therefore, most of the increase emerged from intact to unilateral facetectomy (9.9\%). In total, ROM of lateral bending had the lowest increase with 10.9\% (\textsuperscript{Table 1}).

Axial rotation: In all specimens, ROM increased from intact to unilateral to bilateral facetectomy. The repeated measures ANOVA (p < 0.01) and the Bonferroni correction illustrated that all groups significantly differed from each other. An increase in ROM of 159.9\% was observed. Thereby, there was an increase from intact to unilateral facetectomy of 65.5\% and an increase from unilateral to bilateral facetectomy of 57.1\% (\textsuperscript{Table 1}).

From all these measurements, additional ANOVA models that included the side and the weight effect were calculated. We found no evidence that the first side (right or left) chosen for the removal affects the observed differences in ROM in the three treatment groups. The weight showed significance in flexion–extension and lateral bending; however, the main results remained unchanged.

**Coupled Motion (CM)**

Coupled motion appeared in all three movement directions for intact, after unilateral and after bilateral facetectomy. Flexion–extension was coupled with lateral bending and axial rotation, lateral bending was coupled with flexion–extension and axial rotation, and axial rotation was coupled with flexion–
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and Bonferroni correction showed a significant difference between intact and bilateral facetectomy and between unilateral and bilateral facetectomy. The mean value decreased from intact to unilateral to bilateral facetectomy, with a 16.6% decrease in total (–Table 1). For the other CM, there was no significant influence after facetectomy.

**Coupling Factor (CM/PM)**

The CM/PM was mostly influenced by facetectomy. There was a significant difference after facetectomy in flexion–extension with CM axial rotation ($p = 0.037$), lateral bending with CM axial rotation ($p < 0.01$) and axial rotation with CM flexion–extension ($p < 0.01$) and lateral bending ($p < 0.01$). The coupling factor decreased from intact to unilateral to bilateral facetectomy (–Table 1).

**Symmetry of Motion**

The results showed a significant difference from intact to unilateral to bilateral facetectomy in flexion–extension ($p = 0.042$) and axial rotation ($p = 0.018$; –Fig. 4). Regarding axial rotation, the lowest difference was obtained for intact specimens (24.4%) and in flexion–extension after bilateral facetectomy (8.1%). In lateral bending, the motion was most symmetric after unilateral facetectomy (5%; –Table 1). There was no significant difference when comparing the deflection of the CM to the left with that of the CM to the right side (for lateral bending and axial rotation) and flexion with extension, respectively.

**Discussion**

The main goal of this study was to evaluate how facetectomy may alter the motion pattern of the cervical spine. Results of the present study showed significant influence of motion pattern after facetectomy. Our results suggest that facet joints play a great role in the stability of the cervical spine and act to maintain spatial integrity.

The stability of the cervical spine depends on many factors. The cervical part of the canine spine is reported to be the most flexible of the whole canine column. The findings of previous studies indicate that motion patterns differ significantly between the cranial and caudal cervical spine and that axial rotation occurs to the largest amplitude in the caudal segments. Furthermore, breed-associated differences in vertebral anatomy can have a significant effect on motion.

Specific pathological cervical conditions and mainly caudal cervical spondylomyelopathy may secondarily increase instability at the affected cervical vertebral motion unit. Due to the instability, soft tissues that support and strengthen the cervical articulations proliferate. In the Dobermann, hypertrophy of the inter-arcuate ligament, dorsal longitudinal ligament or dorsal annulus may compress the spinal cord at the vertebral articulations.

The treatment of all these specific pathological conditions has to be modified, depending on clinical presentation, location of the lesion and number of lesions present. Treatment options such as ventral slot procedures, ventral stabilization or alternatively distraction-fusion procedures, disc prosthesis...
Implantation or some combination of these are recommended. Various studies revealed a decrease in ROM when treated with stabilization techniques. This decrease in ROM at the operation site could lead to an increased ROM at adjacent functional spinal units, which could result in an excessive strain and may contribute to recurrence of clinical signs. Decompressive techniques such as ventral slot procedures lead to decreased stability of functional spinal unit through the injury created to the disc system, which may compromise recovery of the animal after surgery. Disc fenestrations also revealed an increased ROM. Although short-term success in all these treatment options is high (80%), the long-term recurrence rate is also quite high (20%). To the authors’ knowledge so far, only one recent study addressed risk factors associated with dorsal or dorsolateral decompression techniques in dogs with osseous-associated spondylomyelopathy. A greater risk of neurological deterioration was detected in these dogs and one hypothesis suggested by the authors was post-surgically increased instability.

Astonishingly, biomechanical studies or investigations concerning cervical facetectomy are sparse in veterinary literature. Crisco and colleagues state a significant increase in ROM after unilevel facetectomy. A human investigation in cervical spines illustrated the importance of facet joints in resisting compression, anterior shear, extension, lateral bending and axial rotation. In the present study, a significant influence of unilateral and bilateral facetectomy on the ROM was found. Therefore, not only ventral slot procedures but also...
Facetectomy in the cervical spine leads to a decreased stability of the functional spinal unit. Compared with ventral slot techniques, in which the ROM increase was at its highest in flexion–extension, the increase in ROM after facetectomy was most remarkable in axial rotation. Previous studies in human medicine have shown that articular facet joints play an important role in resisting axial rotation forces in cervical and lumbar spines and act as a ‘positive stop’ to axial rotation. Although unilateral facetectomy showed the most irregular motion, there was no significant difference in symmetry from intact to bilateral facetectomy. In comparison, after bilateral facetectomy the increase in extension motion was more pronounced than the increase in flexion. (Fig. 2). From a clinical point of view, flexion and extension of the cervical vertebral column are two dynamic factors that might contribute to progression of disease of canine cervical spondylomyelopathy. Extension creates a decrease in the diameter of the vertebral canal and intervertebral foramina, which has been shown to worsen both spinal cord and nerve root compression. In the light of these findings, it might be suggested that the increase in extension motion created by facetectomy leads to an increased instability if the method is used to treat dynamic lesions.

Finally, compared with the other two movement directions, lateral bending showed the most symmetric motion. There was no significant difference in lateral bending from facetectomy and unilaterally.

Table 1 Summary of all specimens with mean and SD

<table>
<thead>
<tr>
<th></th>
<th>PM</th>
<th>CM</th>
<th>Intact</th>
<th>Unilateral</th>
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<td>SD</td>
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Abbreviations: bilat, bilateral facetectomy; CM/PM, coupling factor calculated by dividing CM (°) by PM (°); CM, coupled motion; Ex, part of extension in flexion–extension; Flex, part of flexion in flexion–extension; Lat, lateral bending; PM, primary motion; ROM, range of motion of the primary motion; Rot left, axial rotation to the left side; Rot right, axial rotation to the right side; SD, standard deviation; Sides, unilateral motion to each side; unilat, unilateral facetectomy.

Note: Positive values indicate an increase either from intact to unilateral, from unilateral to bilateral or from intact to bilateral facetectomy. Negative values mark a decrease.

*The difference in percentage (diff. %) between intact specimens and unilateral facetectomy, between unilateral and bilateral facetectomy and between intact specimens and bilateral facetectomy is listed.
Without facet joints, CM decreased, indicating that facet joints play an important role in the coupling effect. Most likely, the geometry of the facet joints may lead to an additional CM compared with the bilateral facetectomized specimens.\(^{22,23,30}\)

Concerning the results of the present study, a couple of limitations should be considered. First, we merely examined the functional spinal unit \textit{in vitro} in cervical spines freed from the stabilizing musculature. However, the lack of musculature \textit{in vitro} does not differ decisively from \textit{in vivo} results.\(^{31}\) The spines underwent freeze–thaw cycles and were stored in the freezer, which could also have altered their mechanical properties. However, various studies showed that storage does not have an influence on the mechanical properties of cadaveric spinal specimens in pigs and humans.\(^{32–34}\) Physical properties only change in the initial freezing cycle.\(^{32}\) Therefore, the assumption is justified that canine cadaveric spines also follow this rule.

In the present study, the sample size of 10 specimens is relatively small for some variables given the relatively high standard deviations and the small differences found (flexion–extension and lateral bending).

Summarizing our results, cervical facetectomy at the C4–C5 facet joints leads to a significantly increased ROM especially in axial rotation and to modified biomechanical patterns. The facet joints seem to confine the ROM and may have an important stabilizing function in preventing hypermobility in all directions. But \textit{in vitro} studies only partially illustrate the changes in stability induced by surgery. Various studies have shown a progressive decrease in instability after surgery, suggesting that biomechanical properties of the cervical spine might change over time.\(^{26,35}\) Cervical spinal treatments requiring a facetectomy should therefore be carefully planned and if an excessive increase in ROM is expected, complications should be prevented by spinal stabilization.

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**Fig. 4** Symmetry of motion for flexion–extension (A), lateral bending (B) and axial rotation (C). On the ordinate, the difference in degrees between flexion and extension (flexion–extension) and between the left and the right side (lateral bending and axial rotation) is listed. Symmetry of motion compared with intact specimens in degrees is listed above the bars. A significant difference between groups is marked with a *: 1, intact specimens; 2, unilateral facetectomy; 3, bilateral facetectomy.

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**References**


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26 Ng HW, Teo EC, Lee KK, Qiu TX. Finite element analysis of cervical spinal instability under physiologic loading. J Spinal Disord Tech 2003;16(01):55–65


