



Investigation of a contributing factor for cervical vertebral stenotic myelopathy using computed tomography for measuring the cervical vertebral volume

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ABSTRACT. Thoroughbred horses appear to be particularly predisposed to cervical vertebral stenotic myelopathy (CVSM), also known as wobbler syndrome. We hypothesized that variations in the cervical vertebral volumes can affect the dynamic instability of the cervical vertebrae. This observational study aimed to clarify whether cervical vertebral volume could be considered as a contributing factor in CVSM in Thoroughbred horses. Computed tomography (CT) was used to investigate a total of 21 male Thoroughbred horses (age range, 217–1,002 days; mean, 542.3 days). The study population comprised 17 CVSM horses (age range, 217–1,002 days; mean, 549.8 days) and 4 non-CVSM horses (age range, 244–682 days; mean, 510.5 days). The cervical vertebral volumes of three-dimensional CT were measured using the image-processing software. A significant difference in the variation of cervical vertebral volumes among C2 to C4 and C3 to C5 was identified in the CVSM group ($P < 0.05$). While no significant differences were found in the variation in cervical vertebral volumes among C4 to C6. C3 demonstrated a significantly smaller cervical vertebral volume than C2 and C4 ($P < 0.05$). In the non-CVSM group, no significant differences were found in the variation of cervical vertebral volume among C2 to C4, C3 to C5, and C4 to C6. Our findings suggest that variations in cranial cervical vertebral volume in CVSM male horses can be considered as an important contributing factor in CVSM development.

KEYWORDS: cervical vertebral stenotic myelopathy, cervical vertebral volume, computed tomography, Thoroughbred horse

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Thoroughbred horses appear to be particularly predisposed to cervical vertebral stenotic myelopathy (CVSM) [7] also known as wobbler syndrome, a developmental orthopedic disease, which is a common cause of cervical spinal cord compression. The primary clinical signs of CVSM include general proprioceptive ataxia and weakness [5, 8]. Some factors in predisposed horses, including nutrition, rapid growth, and exercise, are considered as factors contributing to the development of CVSM [4, 6, 10, 11].

CVSM is divided into two types. Type 1 is characterized by dynamic compression of the cranial portion of the cervical spinal cord (from C2–C3 to C3–C4) that generally affects young horses (8–15 months). Dynamic compression is caused by vertebral malformation and/or malarticulation leading to dynamic instability of the cervical vertebrae [6, 9, 10]. In contrast, type 2 is characterized by static compression of the caudal portion of the cervical spinal cord (from C5 to C7) that generally affects older horses (1–4 years). Static compression is caused by cervical vertebral osteoarthritis and/or thickening of soft tissue [1, 9].

We hypothesized that variations of the cervical vertebral volumes could affect the dynamic instability of cervical vertebrae. A previous study on cervical vertebral length used radiography [2]. And the radiographic study established the generally diagnostic method of CVSM. However, the radiographic findings indicate CVSM rather than the cause of it.

To verify our hypothesis, this study measured the cervical vertebral volume. This observational study aimed to clarify whether the variations in cervical vertebral volume could be considered as a contributing factor in CVSM in Thoroughbred horses.

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MATERIALS AND METHODS

Horses

This study included 21 male Thoroughbred horses (age range, 217–1,002 days; mean, 542.3 days) aged more than 200 days, at which age CVSM is more commonly seen. Computed tomography (CT) was performed on all horses between June 2013 and October 2019 at the Obihiro University of Agriculture and Veterinary Medicine. The study population comprised 17 CVSM samples (age range, 217–1,002 days; mean, 549.8 days) and 4 non-CVSM samples (age range, 244–682 days; mean, 510.5 days), including both living and cadaveric horses. CVSM diagnosis was assessed according to neurological examinations [11], unenhanced radiographs, radiographic myelograms [2], and CT images [12]. Female Thoroughbred horses were excluded from this study. Ample evidence has shown male predominance in CVSM cases [4, 7, 10]. We were few CVSM female horses in our experience. This study's protocol was approved by the Animal Experiment and Welfare Committee of the Obihiro University of Agriculture and Veterinary Medicine (No. 27-127).

CT examination

CT images of the cervical vertebrae were obtained using two CT units that were newly installed during the study period. The first unit was a 4-row multidetector CT (Asteion Super4, Canon Medical Systems Corporation, Ohtawara, Japan) with a gantry opening of 72 cm, tube voltage of 135 kV, tube current of 150 mA, and slice thickness of 2.0 mm, used between 2013 and 2014. The second unit was a 16-row multidetector CT (Aquilion LB, Canon Medical Systems Corp.) with a gantry opening of 90 cm, tube voltage of 135 kV, tube current of 300 mA, and slice thickness of 0.5 mm, used between 2015 and 2019.

Measurements of the cervical vertebral volume

The cervical vertebral volumes were measured using the image-processing software OsiriX-N (Newton Graphics, Sapporo, Japan). The cervical vertebral volume, measured from C2 to C6, was calculated for each vertebra. The reason for selecting this range was that C1 was closely articulated with the skull; thus, the delineation of C1 was difficult to perform, and C7 was located near the shoulder. In this study, fitting the entire neck into the gantry whose size was smaller than the shoulder of certain adult horses was impossible. Therefore, we measured the volumes from C2 to C6 to keep number of the samples. The area of cervical vertebrae (200–1,500 HU) was measured in the two-dimensional transverse plane. Then, three-dimensional images, used to calculate the cervical vertebral volume, were reconstructed using the volume rendering technique (Fig. 1).

Investigative analyses

Two investigative analyses were performed to distinguish between the different properties of the CVSM and non-CVSM groups. In the first analysis, each cervical vertebral volume was compared between the CVSM and non-CVSM groups. In the second, the variation of each cervical vertebral volume was compared among the other volumes (i.e., C2 to C4, C3 to C5). In case of significant

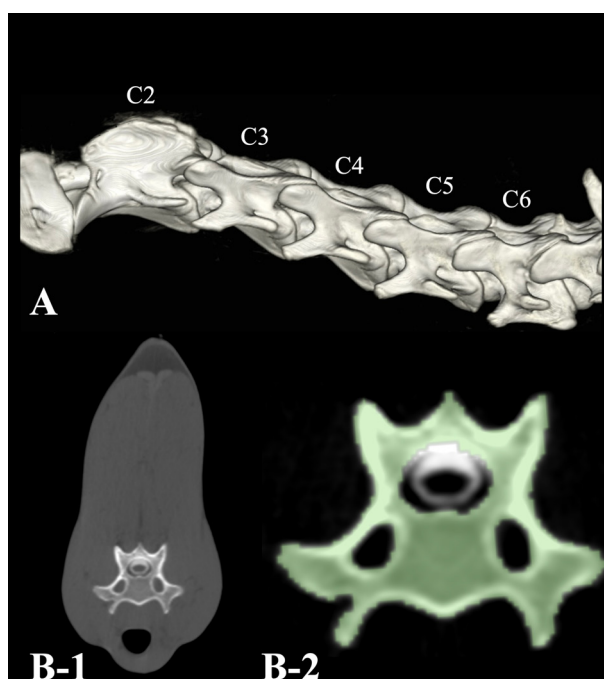


Fig. 1. The cervical vertebral volume measurements ranged from C2 to C6 (A). The cervical vertebral area (200–1,500 HU), wherein the region of interest was shown the green area, was measured in the two-dimensional transverse plane (B-1, 2). Three-dimensional images were reconstructed using the volume rendering technique to calculate the cervical vertebral volumes.

differences among the cervical vertebral volumes, each cervical vertebral volume was compared with the next one (i.e., C2 and C3, C3 and C4) by statistical analysis.

Statistical analysis

Excel software (Mac for Excel, Microsoft Japan, Tokyo, Japan) was used for data processing and analysis. First, logarithm regression equations were calculated by the measured values. Second, prediction values of the cervical vertebral volume in CVSM or non-CVSM were calculated by replacing the logarithm regression equation with the horse's age.

The prediction values of each cervical vertebral volume between CVSM and non-CVSM horses were compared using unpaired Welch's *t*-test. Each cervical vertebral volume was compared with the next two cervical vertebral volumes using one-way analysis of variance (ANOVA). A *P*-value of less than 0.05 was considered significant.

RESULTS

Comparison of cervical vertebral volume between the CVSM and non-CVSM groups

No significant differences were found in the cervical vertebral volume between the CVSM and non-CVSM groups (Table 1).

Comparison among each cervical vertebral volume

In the CVSM group, a significant difference in the variation of cervical vertebral volumes was identified among C2 to C4 and C3 to C5 ($P < 0.05$). In contrast, no significant differences were noted among C4 to C6. Furthermore, C3 demonstrated a significantly smaller cervical vertebral volume than C2 and C4 ($P < 0.05$; Fig. 2). In the non-CVSM group, no significant differences were found in the variation of cervical vertebral volume among C2 to C4, C3 to C5 and C4 to C6 (Fig. 3).

DISCUSSION

Type 1 of CVSM is caused by vertebral malformation and/or malarticulation leading to dynamic instability of the vertebrae, which is generally observed in the cranial portion of the cervical spinal cord (from C2–C3 to C3–C4) [9]. Our findings showed that C3 in CVSM horses demonstrated a significantly smaller cervical vertebral volume than C2 and C4. Consequently, it can be suggested that the size of C3 in CVSM horses is inefficient to articulate with cranially or caudally cervical vertebrae, and variations of cervical vertebral volumes in CVSM is presented in the cranial portion of the cervical vertebrae. Furthermore, the cranial cervical vertebral area (C2–C4) exhibits inefficient strong ligaments [3]. Horse cervical vertebrae were lined up in an S-shaped arrangement, with load deflection points on C3–C4. In the view of the principle of leverage, the point of C3–C4 serves as the fulcrum point, and the head serves as the application point. The movement of the head affects dorsoventral stress in C3–C4 owing to the up-and-down sequence of motion during galloping. Hence, variations in the cranial cervical vertebral volumes in CVSM male horses and inefficient strong

Table 1. Results of comparison of cervical vertebral volume between the cervical vertebral stenotic myelopathy (CVSM) and non-CVSM groups

	C2	C3	C4	C5	C6
<i>P</i> value	0.57	0.81	0.67	0.63	0.71

No significant differences were found in the cervical vertebral volume between the CVSM and non-CVSM groups.

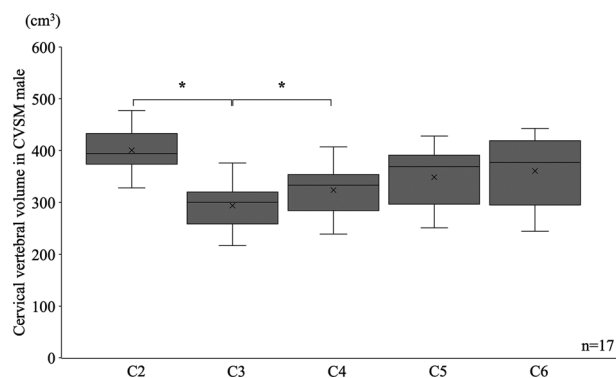


Fig. 2. Box-and-whisker plot of cervical vertebral volumes in cervical vertebral stenotic myelopathy horses. C3 demonstrated a significantly smaller cervical vertebral volume than C2 and C4 ($*P < 0.05$).

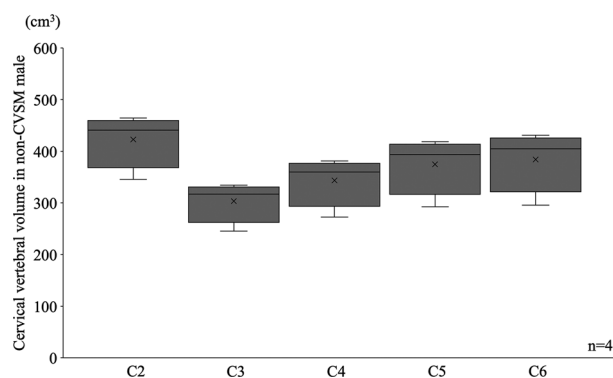


Fig. 3. Box-and-whisker plot of cervical vertebral volumes in non-cervical vertebral stenotic myelopathy horses. No significant differences were found in the variation of cervical vertebral volumes.

ligaments cannot be resistant to head movements that affect the dorsoventral moment. Meanwhile, the caudal cervical vertebral joint had adequate strength in Thoroughbred horses [3]. Therefore, it was considered that the prevalence of CVSM type 1 was shown in C2–C3 and C3–C4.

Previous studies have shown that male horses are more prevalence of CVSM [4, 7, 10]. The limitation of the present study is that sex differences in the cervical vertebral volume were not discussed because the number of female samples was very small. In the future, we aim to measure the cervical vertebral volume in female horses to perform a comparative study with our present findings.

Conclusively, our findings suggest that variations in cranial cervical vertebral volume in CVSM male horses can be considered as an important contributing factor in CVSM development.

CONFLICT OF INTEREST. The authors declare that there were no conflicts of interest.

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