Biomechanical comparison after in vitro laminar vertebral stabilization and vertebral body plating of the first and second lumbar vertebrae in specimens obtained from canine cadavers

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Objective—To compare biomechanical characteristics of vertebral segments after vertebral body plating or laminar stabilization following complete incision of the annulus fibrosus.

Sample—Vertebral segments from T13 through L3 obtained from 18 canine cadavers.

Procedures—A 4-point bending moment was applied in flexion and extension to the intact vertebral segments to determine a baseline range of motion (ROM) and neutral zone (NZ). Vertebral columns were then destabilized by creating a defect in the intervertebral disk via complete incision of the ventral aspect of the annulus fibrosus. The bending moment was applied again after stabilization was accomplished via vertebral body plating or with laminar stabilization (n = 9 vertebral segments/stabilization technique). The ROM and NZ were compared with their baseline values and among treatment groups. Finally, load-to-failure testing was performed in flexion.

Results—Mean relative ROM and NZ for segments treated with laminar stabilization were significantly lower than those for segments treated with vertebral plates.

Conclusions and Clinical Relevance—Analysis of in vitro results suggested that laminar stabilization of vertebral segments provided greater stiffness than did vertebral body plating. (*Am J Vet Res* 2011;72:1681–1686)

Various methods have been described for the surgical treatment of dogs with vertebral instability. The most frequently used techniques comprise vertebral body stabilization by use of plates or PMMA and pin-and-screw composite fixation.[1–4] Complications associated with these techniques include penetration of the thorax, damage to vascular structures, pin loosening, and infection or host reactions associated with PMMA.[3] The need for vertebral column stabilization after decompressive surgery of the spinal cord has been advocated by some authors.[5–7] Indeed, ventral decompression of thoracolumbar Hansen type II disk herniation with lateral corpectomy results in removal of a large amount of the vertebrae, which results in an unknown degree of instability.[8] Currently used dorsal stabilization techniques, such as tension band fixation, provide sufficient stability in small dogs but appear to provide insufficient stability in large dogs, which necessitates other methods of stabilization.[9] However, laminar stabilization provides an advantageous lever arm because the predominant movement in the thoracolumbar region is flexion with the intervertebral disk at the center of motion.[10,11] It is unclear whether this tension band effect may avert early implant loosening, which can be observed in ventral body plating.

ABBREVIATIONS	
NZ	Neutral zone
PMMA	Polymethylmethacrylate
ROM	Range of motion

A novel alternative method of vertebral stabilization is the use of laminar plates. The rationale for laminar stabilization is to benefit from dorsal fixation and provide increased stability by penetrating more of the cortices. A safe corridor for screw insertion was established by use of computed tomography in another study[12] conducted by our research group, but biomechanical testing has not been performed.

The best comparison for implants in vertebral biomechanics involves testing under controlled loading conditions in vitro.[13–16] The primary stiffness afforded by implants can be described in terms of the ROM and NZ of the vertebral specimen instrumented with the implant of interest. The NZ describes the range over

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which the specimen moves essentially free of an applied load (eg, under its own weight). The ROM is the sum of the deformation of the NZ and the deformation measured from the end of the NZ to the point of maximal loading (elastic zone).[13] The purpose of the study reported here was to compare the biomechanical characteristics of vertebral body and laminar vertebral stabilization.

Materials and Methods

Sample population—Vertebral specimens (T13 through L3) were harvested from 18 cadavers of dogs euthanized for reasons unrelated to the study. All dogs were > 1 year old and weighed between 18 and 35 kg. Surrounding soft tissue was removed from the vertebrae, but the supporting ligaments were allowed to remain intact. Specimens that appeared pathologically altered on the basis of gross examination or fluoroscopic examination were excluded. Each segment was sealed in a plastic bag and stored at –20°C for subsequent use in the study.

Experimental design—Vertebral segments were allocated to 2 groups (9 segments/group). Of the 18 segments, 9 were used for fixation of L1 and L2 via vertebral body plating and 9 were used for fixation of L1 and L2 via a laminar vertebral stabilization technique. Biomechanical assessment of each specimen was performed before and after incision of the annulus fibrosus and vertebral stabilization. Mechanical properties were compared within each specimen.

Specimen processing—Specimens were thawed at 21°C for 12 hours before testing. Width of the vertebral bodies of L1 and L2 was measured at a point immediately caudal to the transverse processes. The ends of the vertebrae were potted into square metal tubes (46 X 46 mm) by use of PMMA, with additional wood screws inserted for reinforcement **(Figure 1)**. Position of the screws was assessed via fluoroscopy. The PMMA was allowed to dry in air for approximately 1 hour prior to testing. Segments cranial (T13 and L1) and caudal (L2 and L3) to the implant were stabilized with screws inserted axially through the vertebral body, which allowed the L1 and L2 segment to be stabilized with either technique and then tested. Fluoroscopy was used to confirm accurate positioning. Throughout testing, specimens were kept moist by wrapping them in towels soaked with saline (0.9% NaCl) solution.

Testing system—A 4-point bending test with the vertebral segment in flexion and extension was performed in a servohydraulic testing machine[a] (Figure 1). Three cycles of 0 to 3 N•m were applied to the intact unplated vertebral segment in flexion and extension to establish baseline values for segmental motion. Crosshead displacement and applied force were recorded. After initial testing, a defect was created in the annulus fibrosus of the intervertebral disk (L1-2 disk) by ventral incision of the entire disk with a No. 11 scalpel blade. Surgical stabilization was then performed. Testing was repeated with the vertebral segment in flexion and extension by use of the same settings for each specimen. Finally, a load-to-failure test was performed with each vertebral segment in flexion.

Vertebral body plating—A 5-hole 2.7-mm reconstruction plate[b] was affixed on the lateral aspect of the vertebral body for the vertebral body group. Each vertebral body was stabilized with 2 screws.[c] Drilling was performed at an angle of 60° toward the vertical axis, as described elsewhere.[16,d] Care was taken to avoid

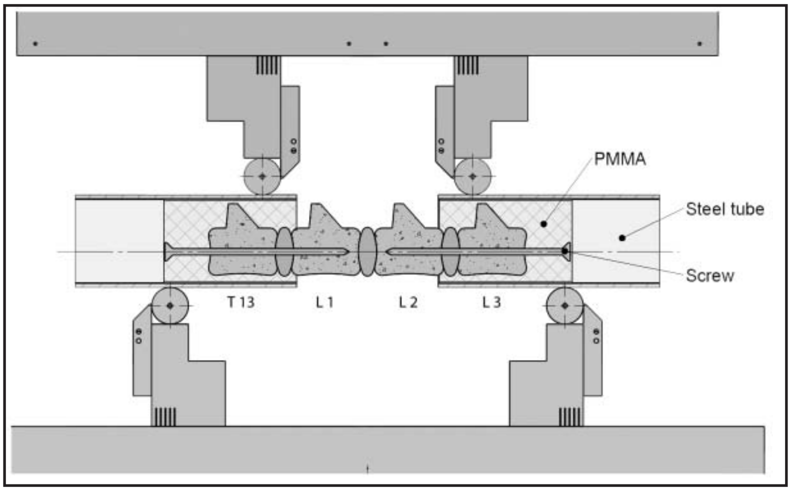

Figure 1—Schematic of the biomechanical testing system for fixation of canine vertebral specimens (T13 through L3) with a screw inserted axially in each vertebral body and PMMA filling the space between each vertebra and steel tube. In this configuration, extension is being applied. The apparatus is turned to apply flexion.

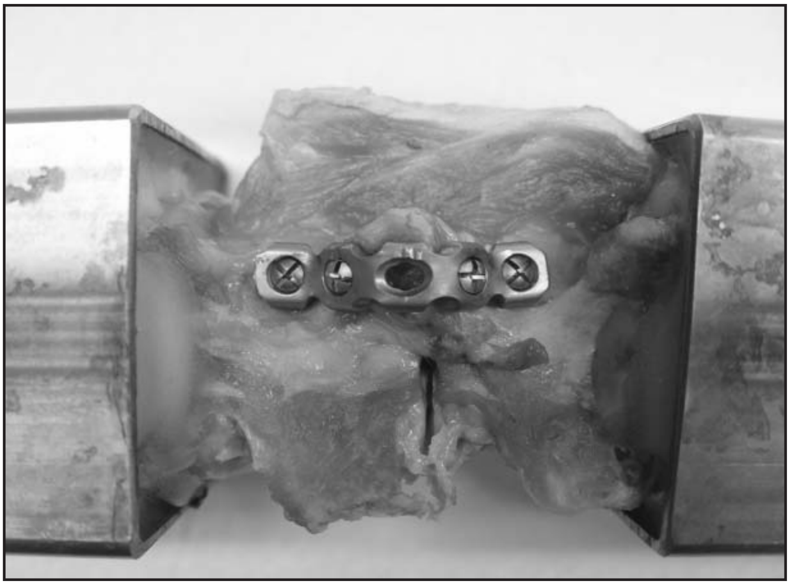

Figure 2—Photograph of the lateral aspect of a vertebral specimen embedded into PMMA and fit into square metal pipes. A defect has been created in the ventral area of the intervertebral disk. The laminar stabilization technique involves application of the implant around the facet joint.

Table 1—Range of motion and NZ measurements for 9 canine vertebral segments that received vertebral body plates and 9 canine vertebral segments that received laminar stabilization.

	Vertebral body*									Laminar*								
Variable	8	9	10	13	15	19	20	22	24	6	7	11	14	16	17	18	21	23
ROM intact (°)	25.02	23.15	21.33	26.99	20.63	23.17	11.87	15.96	17.4	30.67	21.41	21.25	33.99	21.44	16.43	14.16	16.48	12.19
ROM plated (°)	23.63	33.57	21.12	32.59	22.22	23.64	11.28	18.52	21.51	22.98	18.01	19.07	29.76	15.91	11.01	8.36	11.53	7.35
Plated ROM (% of intact)	94.44	145.01	99.02	120.75	107.71	102.03	95.03	116.04	123.62	74.93	84.12	89.74	87.56	74.21	67.01	59.04	69.96	60.30
NZ intact (°)	12.26	11.62	11.57	14.02	11.06	10.65	4.85	7.14	7.23	14.68	9.69	10.65	18.55	12.8	7.15	6.18	8.89	4.73
NZ plated (°)	10.75	21.63	12.89	18.05	9.17	11.86	4.61	8.25	14.34	10.08	8.48	10.16	16.86	7.69	5.59	3.44	5.35	3.49
Plated NZ (% of intact)	87.68	186.14	111.41	128.74	82.91	111.36	95.05	115.55	198.34	68.66	87.51	95.40	90.89	60.08	78.18	55.66	60.18	73.78
Failure moment (N•m)	14.02	11.04	13.09	10.25	15.79	17.14	23.31	15.10	10.43	19.28	17.24	13.79	17.33	20.85	14.49	30.93	15.50	25.90
Failure angle (°)	33.76	31.48	28.09	31.15	23.96	36.96	26.45	23.56	20.86	40.37	35.87	23.12	43.89	32.55	28.61	33.45	27.25	28.73

The absolute values in degrees as well as the values of treated specimens relative to the untreated specimens are provided. Data for the load to failure are also included.

*Numerals indicate the specimen numbers.

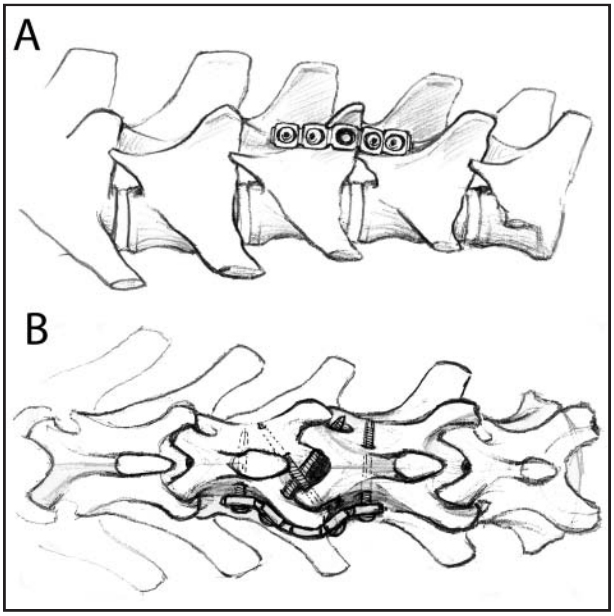

Figure 3—Drawings of the lateral (A) and dorsal (B) views of a canine vertebral segment indicating the position of the implant applied for laminar stabilization. Notice the position of the plate dorsal to the vertebral canal but ventral to the spinous process on the lateral view. On the dorsal view, notice that the 2 cortical screws are inserted at an angle such that they cross and that the implant is bent around the facet joint; this necessitated maximum bending of the implant.

placement of screws in the intervertebral disk. During plating, gross examination of each specimen for pathological changes (eg, spondylosis, bony masses, or other malformations) was performed.

Laminar stabilization—A 5-hole, 2.7-mm reconstruction plate,[b] which was bent to fit around the facet joint, was used for the laminar group (**Figure 2**). One screw[c] was inserted from the left side into the lamina in each vertebra, and the facet joint was stabilized by insertion of two 2.7-mm cortical screws[c] that were angled such that they crossed each other (**Figure 3**). Drilling was performed in an almost horizontal direction (intended angle, 5° toward ventral) by use of a drill guide[e] to estimate the exit point on the transcortex. During implantation, gross examination of each specimen for pathological changes (eg, spondylosis, bony masses, or other malformations) was performed.

Implant assessment—A load-to-failure test was performed, and the location of failure within the PMMA-vertebrae construct was recorded. The screws were inspected for subjective assessment of loosening (torque force was not recorded), and the position of loose screws was recorded.

Data analysis—Values for segmental angulation and applied moment were derived from the recorded force and displacement data and the geometric relationship of the 2 cortical screws and the potting fixture. Moment-angle curves were used to calculate NZ and ROM. The relative change of ROM and NZ after removal of the annulus fibrosus and surgical stabilization was calculated for each specimen. Those values were compared by means of a 1-way ANOVA with a Tukey post hoc test. Values of $P < 0.05$ were considered significant.

Results

Specimen size—Mean width of the vertebral body was 21.0 mm (range, 18.3 to 25.0 mm) for L1 and 21.2 mm (range, 18.5 to 24.6 mm) for L2 for the 9 vertebral segments in the vertebral body group. Mean width of the vertebral body was 21.3 mm (range, 18.0 to 23.8 mm) for L1 and 21.6 mm (range, 18.5 to 24.0 mm) for L2 for the 9 vertebral segments in the laminar stabilization group.

Biomechanical data—The mean ROM and NZ of the 3 loading cycles were recorded for all specimens before and after treatment. Values for the untreated intact

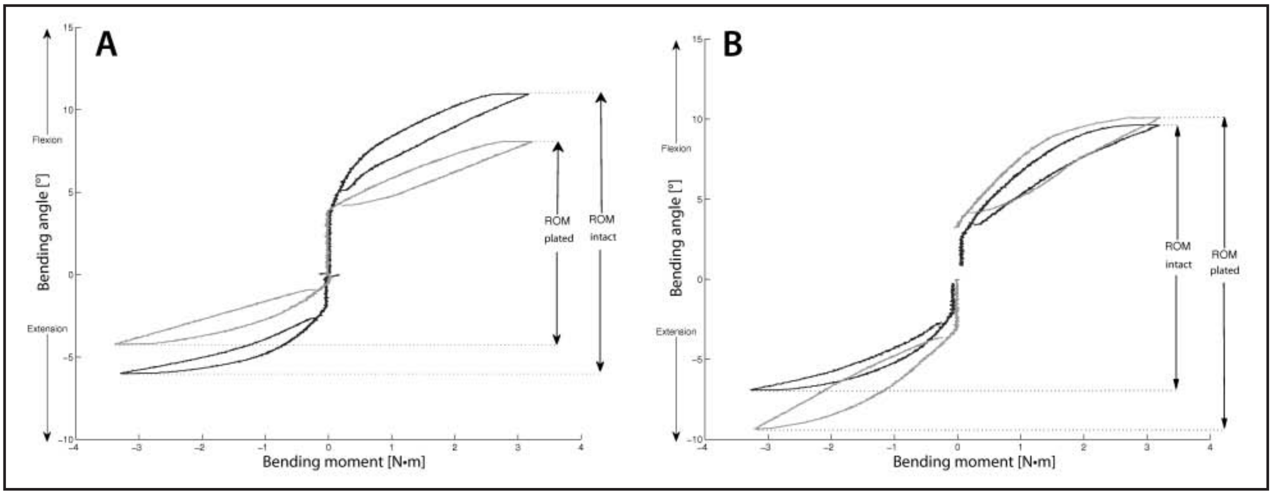

Figure 4—Moment-angle curves for a canine vertebral segment with stabilization via laminar stabilization (A) and via vertebral body plating (B). In each panel, the curves for the stabilized (gray lines) and unplated intact (black lines) vertebral segments are indicated. For the vertebral body plate, there is reduced stiffness and increased ROM of the segment, whereas for the laminar stabilization, there is increased stiffness and ROM of the segment. Flexion is indicated in the upper right part of each graph as a positive bending moment and positive bending angle. Range of the ROM of the intact and stabilized vertebral segments is indicated on the right side of each panel.

specimens were set at 100%, and mean values for ROM and NZ after treatment were calculated relative to the values for the untreated intact specimens **(Table 1)**.

The difference between the mean relative ROM of the laminar stabilization group and vertebral body group was 37.42%, with a significantly ($P = 0.01$) lower relative ROM for the laminar stabilization group. Similarly, the difference between the mean relative NZ of the laminar stabilization group was significantly ($P = 0.01$) lower (49.65% less) than the difference for the mean relative NZ of the vertebral body group.

Evaluation of moment-angle curves of individual specimens suggested a reduction in stiffness and increased ROM after vertebral body plating, compared with results for unplated specimens **(Figure 4)**. Similarly, there was increased stiffness and decreased ROM after laminar plating, compared with results for unplated specimens.

Specimen and implant assessment—Load-to-failure testing resulted in bony failure in the facet joints of the stabilized segment (L1 and L2) in 8 specimens and failure in the facet joint of the cranial segment (T13 and L1) in 1 specimen in the vertebral body group. Construct failure was observed in the cranial (T13 and L1), caudal (L2 and L3), or both cranial and caudal segments in the laminar stabilization group. However, the stabilized segment (L1 and L2) remained intact in all 18 specimens. Loosening of screws was observed in 5 of 9 specimens in the vertebral body group with between 1 and 4 loosened screws/specimen. Loosening of 2 screws (the cranial and caudal screw inserted in the lamina) was observed in 1 specimen of the laminar stabilization group. Load-to-failure testing revealed a mean ± SD failure load of 14.46 ± 4.11 N•m for the vertebral body group and 19.48 ± 5.67 N•m for the laminar stabilization group, with a mean failure angle of 28.48 ± 5.28° and 32.65 ± 6.60°, respectively.

Discussion

Analysis of results of the study reported here revealed a significant reduction in the ROM in segments treated via laminar stabilization, compared with that for segments treated via vertebral body plating. The L1 and L2 vertebral segment was chosen for evaluation in this study because thoracolumbar disk disease develops commonly (85% of cases) between T12 and T13 and between L2 and L3 in chondrodystrophic breeds and most frequently between L1 and L2 in large-breed dogs.[3,17,18] Vertebral fractures and luxations generally occur at junctions between mobile and immobile sections of the vertebral column, and the thoracolumbar area (T3 through L3) is most frequently affected in dogs.[18,19] The need for vertebral column stabilization following disk compression remains unclear, but it is recommended by some authors.[5–7,20] Although it is unknown whether lateral corpectomy creates relevant instability of the vertebral column, the amount of instability has been reported for intervertebral disk fenestration and hemilaminectomy.[20] Moreover, it has been proposed[6] that stabilization of a vertebral segment may prevent further disk protrusion and promote long-term atrophy of protruded disk material. However, studies have not been conducted to directly compare results for stabilization and decompression with those for decompression alone.

Biomechanical characteristics of vertebral stabilization implants have been evaluated for some of the various techniques described.[14,16,20–24] In 1 biomechanical study[23] conducted to compare the rigidity in flexion for 5 internal fixation techniques (vertebral body plating, vertebral body crosspins, PMMA and pins, plastic plates applied to the spinous processes, and a combination of vertebral body plating and spinous process plating), vertebral body plating was the technique with the strongest rigidity. The strongest fixation was a combination of vertebral plating and dorsal vertebral plating, but even this was found to be insufficiently rigid.[23] In that study,[23] plating of the spinous processes with plastic plates appeared to provide stiffer fixation than did the combination of pins and PMMA inserted on the vertebral body. However, internal fixation with screws and PMMA was found to provide the greatest stability and strength in rotation in another study.[25] The results of that study[25] indicated a remaining ROM comparable to that of another study[26] for vertebral stabilization. Analysis of results for dorsal laminar stabilization indicates an increased stiffness in flexion and extension, on the basis of a biomechanical study[27] from human medicine. That study[27] revealed comparable results for posterior systems, although the most rigid stabilization was achieved by a comparison of dorsal and ventral techniques.

It requires several weeks for a stabilized vertebral fracture to heal, during which thousands of loading cycles affect the vertebral fixation. Disruption of the fixation may lead to further neurologic deterioration, especially in larger dogs. Optimal rigid internal fixation should avoid this and minimize formation of a large callus, which may cause stenosis of the vertebral canal.[23] We have observed implant loosening with various stabilization techniques; thus, the objective of the study reported here was to evaluate the stiffness of laminar and vertebral stabilization to avoid insufficient stabilization. The precise amount of vertebral stability and the maximum vertebral canal angulation required to achieve this have not been elucidated.[23,28] Until that time, implants can only be compared on the basis of biomechanical data and clinical experience.[23,28]

The musculotendinous apparatus was not considered in the biomechanical method used in the present study, although this method is an accepted standard for in vitro preclinical evaluation of vertebral stabilization techniques and has been used by many other investigators in veterinary studies.[16,21–23,29] Therefore, the clinical impact of the techniques investigated on muscular stabilization remain unclear.

In vivo, the musculoskeletal apparatus is thought to play an important role in vertebral stability,[23] although it is unclear whether the paravertebral muscles exert much stabilizing effect in paralyzed patients.[30] However, if muscular support is considered important during the recovery period, a superficial approach with minimal soft tissue disruption, such as that used with laminar stabilization, may be superior to techniques that require deep placement of a plate on the vertebral body.

The predominant motion in the thoracolumbar vertebrae in dogs is that of flexion, which is thought to play an important role in the development of vertebral injuries and in the failure of vertebral implants.[31–34] Moreover, flexion is believed to be the most difficult force to counteract during the postoperative period. Indeed, a back splint can easily resist vertebral extension and lateral bending but not flexion.[23] In addition, flexion is the force by which a plate on the dorsal aspect acts as a lever arm because the plate is located distant from the center of motion at the intervertebral disk. Given these facts, the present study was designed to determine ROM in flexion and extension and to load the construct to failure in flexion for a dorsal and a ventral stabilization technique.

Vertebral body plating is commonly performed with standard dynamic compression plates, but locking systems have also been described.[6] In the present study, laminar stabilization could not be performed with a standard dynamic compression plate because the 3-D bending around the facet joint was not feasible and a reconstruction plate would have been needed to perform the amount of bending necessary.

A further advantage of laminar plating observed in the present study was the low number of loose screws, compared with the number of loose screws for vertebral body plating. Placement of screws in the intervertebral disk has been implicated in loosening of vertebral body plate screws in another report.[5] However, none of the loose screws in the study reported here were located in the disk space, which suggested an increased load on screws in vertebral body plates, compared with the load on screws in laminar plates. Values for the load to failure and the angles in the vertebral body group were lower than those in the laminar group where the constructs failed. This suggested that they resisted greater bending forces, even though the amount of stability needed to stabilize a vertebral segment is unknown. The failure was observed for the vertebral body group in the facet joint of the segment to which the plate was applied. In contrast, the failure for the laminar stabilization group was observed in segments next to the stabilized segment. The laminar stabilization group may even have resisted a greater load.

Analysis of results of the study reported here suggested superior vertebral stability for laminar stabilization, compared with that for vertebral body plating, but the clinical benefit of the laminar stabilization technique remains to be proven. Laminar stabilization may find application in vertebral column stabilization following vertebral fractures or luxations and decompressive surgery, for animals with diskospondylitis, and in corrective surgery for vertebral malformations. The technique might be a general alternative to vertebral body plating or as an alternative when a defect or infection makes it impossible to apply a plate to the lateral side of a vertebral body.

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a. MTS Bionix 858, MTS Systems, Eden Prairie, Minn.

b. Reconstruction plate 2.7, Synthes, Solothurn, Switzerland.

c. Unilock 2.4 System, Provided by Synthes, Solothurn, Switzerland.

d. Walker TM, Tucker R, Welsh RD, et al. Fluoroscopic placement of transfixation pins for the external skeleton fixation of the canine spine: an anatomical study (abstr). *Vet Comp Orthop Traumatol* 2001;14:A13.

e. Veterinary Instrumentation, Sheffield, South Yorkshire, England.

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