Angle of insertion and confirmation of angles measured after in vitro implantation during laminar vertebral stabilization in vertebral columns obtained from canine cadavers

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Objective—To determine angles of insertion for laminar vertebral fixation of L1 and L2 by use of a locking plate in dogs and to confirm screw placement by use of computed tomography (CT).

Sample—Vertebral specimens harvested from 8 canine cadavers.

Procedures—The point of insertion and minimum and maximum insertion angles for laminar and facet screws for laminar vertebral stabilization were determined by use of CT. A precontoured locking plate was then placed by use of 1 locking screw in the lamina of each lumbar vertebra and 1 nonlocking screw in the facet joint. The position and angle of the screws were examined by use of CT, and penetration into the vertebral canal was recorded.

Results—Mean ± SD insertion angles for L1 and L2 were 18 ± 4° and 21 ± 5° toward the vertebral canal and 11 ± 4.4° and 10 ± 3° in a dorsal direction, respectively. Insertion angles for the facet joint were between 24 ± 4° ventrally and 12 ± 2° dorsally. Insertion of the screw did not penetrate the vertebral canal for 23 of 24 (96%) screws. For 23 of 24 inserted screws, the previously determined angle was maintained and purchase of bone and cortices was satisfactory.

Conclusions and Clinical Relevance—Placement of laminar and facet screws in canine vertebrae was possible and can be performed safely if angles of insertion determined preoperatively via CT are maintained. (*Am J Vet Res* 2011;72:1674–1680)

Surgical stabilization is indicated for the treatment of a variety of vertebral conditions in dogs, including fracture or luxation,[1,2] lumbosacral instability, diskospondylitis,[1] and congenital malformation.[3] In addition, some authors recommend vertebral stabilization following spinal cord decompression via hemilaminectomy or corpectomy.[4–8]

Several techniques of vertebral stabilization have been described in dogs. Pins or screws and polymethylmethacrylate,[1] vertebral body plates,[9] and most other implants are inserted into the ventral aspect of the vertebral body, although screw or pin loosening and migration, infection, and cement breakage are problems reported with this technique as well as with techniques for dorsal insertion.[10–12] Furthermore, major vessels, peripheral nerves, and the thoracic cavity are located ventral to the thoracolumbar vertebral bodies and are at risk of injury. Fluoroscopy has been used to minimize iatrogenic soft tissue damage and to provide safe insertion of implants.[13–15] In contrast, dorsal vertebral plating, dorsal vertebral stapling,[16] and tension-band fixation[17] involve use of the dorsal part of the vertebrae to stabilize the vertebral column, which thus averts potential damage to ventrally located soft tissues. Although biomechanics of injured lumbar vertebrae may differ, the predominate motion in intact vertebral columns is flexion, which can be counteracted by dorsal fixation techniques that act as a tension band.[18,19]

Dorsal stabilization involves the use of the spinous process for implant insertion, but bone purchase is limited. Laminar stabilization is a novel technique that has the advantages of dorsal fixation with additional cortical layers providing stability and involves a surgical approach that is easy to perform. Nevertheless, laminar stabilization involves the risk of spinal cord damage, and care must be taken to avoid such damage.

To our knowledge, guidelines for safe and optimal implantation have not been established for laminar fixation in dogs but are necessary prior to recommending its use in clinical practice. Implantation angles for other vertebral fixation techniques have been established by use of CT.[20–22,a] The purpose of the study reported here

Abbreviations

CT	Computed tomography
HU	Hounsfield unit
POI	Point of insertion

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was to determine via CT the point and angle of insertion and safety of laminar stabilization of L1 and L2 in dogs by use of a locking plate for preoperative and postoperative control.

Materials and Methods

Sample—Vertebral columns, including the paraspinous musculature and the supporting ligaments, were harvested from cadavers of 8 dogs (6 Beagles and 2 mixed-breed dogs) euthanized for reasons unrelated to the study. Body weight of each dog at the time of euthanasia was recorded, and cadavers were stored at –20°C and thawed at 21°C for 12 hours prior to the study. Pathological changes were detected via CT and via gross examination during implantation.

Study design—Computed tomography was performed before and after unilateral laminar plating of L1 and L2. The desired angle of insertion of the screws was measured before plating and evaluated in the postoperative CT of the vertebral column. All measurements and laminar fixations were performed by the same investigator (SCK).

CT evaluation—A multislice helical CT scanner[b] was used to obtain images of T13 through L3. Technique settings were peak voltage of 120 kV, 250 mA (rotation time, 1 second) with 2-mm collimation, and pitch of 0.5 (slice thickness, 2 mm; bone window) in an extended HU scale.[c] Images were reconstructed in an extended HU scale in 0.6-mm slices in a high-contrast algorithm and evaluated in a bone window (window level, 300 HUs; window width, 1,500 HUs). Analysis was performed by use of imaging software.[d]

Implants—Laminar fixation was provided by use of a 5-hole locking plate[e] with 2 locking screws (3.0 mm) inserted on the lateral surface of L1 and L2, respectively, and 1 nonlocking screw (2.4 mm) inserted in the facet joint (**Figure 1**). Laminar screws (locking screws inserted in the dorsal lamina of L1 and L2) and the facet screw (a nonlocking screw inserted into the facet joint between L1 and L2) were examined separately.

Implant measurements—Measurements were determined on CT images obtained for 3 insertion points. To measure the insertion angle, a POI was defined corresponding to the position of the screws. These were the middle of L1 (insertion of the cranial laminar screw), the L1-2 facet joint (insertion of the facet screw), and the middle of L2 (insertion of the caudal laminar screw). The points for L1 and L2 were defined in the center of the vertebra in the transverse section of the CT image. The center was considered the middle of the long axis of the vertebra measured in the sagittal section. For the laminar screws, the center was located in the preoperative image as the most cranial part of the base of the articular facet (the transition from the dorsal lamina to the pedicle surrounding the vertebral canal on the lateral side in a horizontal plane; **Figure 2**). The POI for the facet joint was located dorsal to the intervertebral disk in the transverse section. It was at a point 0.6 cm ventral to a horizontal line drawn between the dorsal rims of the contralateral 2 facet joints (**Figure 3**). This distance was based on the position of the plate because the plate was placed with its dorsal rim attached tangential to the dorsal border of the facet joint. The distance of 0.6 cm was half the width of the 5-hole locking plate and the point at which the center of the screw was located.

From these points, a minimum and a maximum angle of insertion was determined in relation to a horizontal line that passed through the transition from the dorsal spinous process and the dorsal lamina of the vertebral canal. The maximum angle was defined as the angle for which the screw would be placed as close as

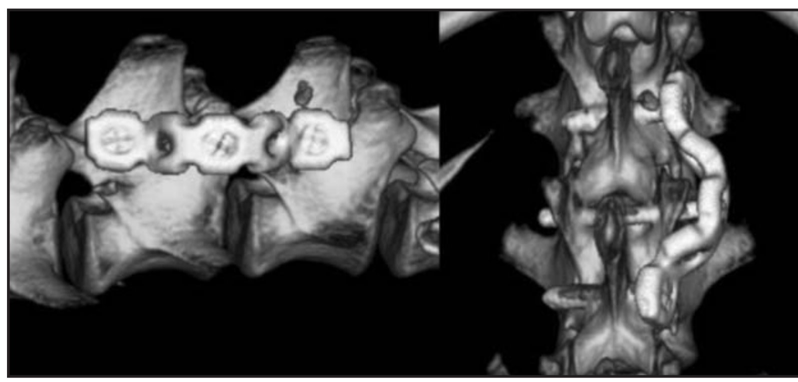

Figure 1—Two 3-D CT reconstructions of a vertebral column obtained from a canine cadaver. The lateral (left) and dorsoventral (right) views reveal the position of a plate with laminar screws inserted in L1 and L2 and a facet screw inserted in the L1-2 space. The POI is at the most cranial point of the articular facet and can be located by sliding the precontoured plate ventrally on the articular facet until it rests on the laminar bone.

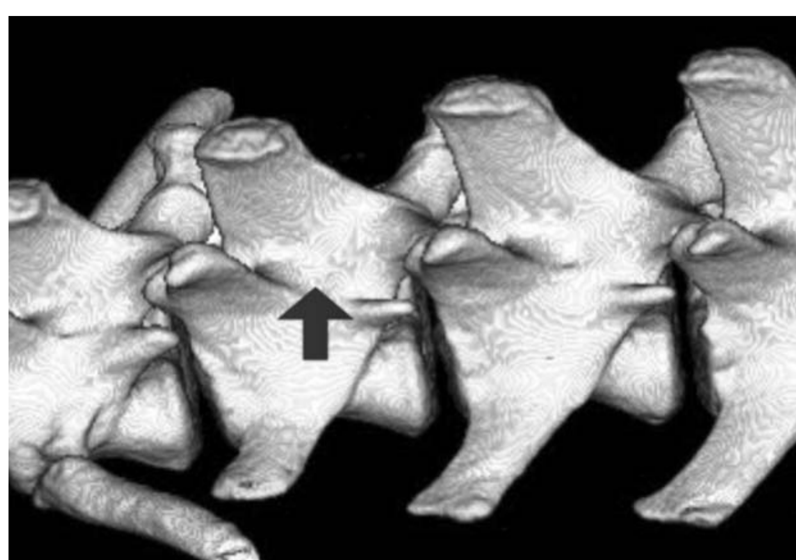

Figure 2—A 3-D CT reconstruction of the vertebral column obtained from a canine cadaver. Notice the POI for the laminar screw in L1 (arrow). This point needs to be identified by the surgeon.

possible to the vertebral canal without penetrating it. The minimum angle was the angle that included 2 cortices of the lamina below the base of the spinous process. This angle was set as a negative value such that screw placement at a more negative angle would penetrate only the spinous process, thereby providing inadequate stability (**Figure 4**). Minimum and maximum angles were similarly defined for the nonlocking facet screw (Figure 3). For the nonlocking facet screw, the maximum angle was the most ventral angle that would not result in damage of the vertebral canal. The minimum angle was the most dorsal angle that included cortices of the facet joint; this angle was set as a negative value.

After laminar stabilization, the position of the screws was analyzed on postoperative CT images. Images were examined for evidence of penetration of screws into the vertebral canal, insertion angles, comparison of the POI with preoperative measurements, cortices penetrated by the screw, and placement into the spinous process or dorsal to the facet joint.

Points of insertion determined before implantation were compared with position of the screws determined by evaluation of postoperative CT images. The distance between these 2 points along a tangential line representing the cortical layer was measured (**Figure 5**). Mean deviation and range of the values were recorded.

Surgical stabilization technique—A dorsolateral approach was performed on the right side of each vertebra; each vertebra was positioned on its ventral surface, which corresponded to a patient in sternal position. The lumbodorsal fascia was incised over 4 vertebrae lateral to each spinous process. Muscles were retracted, and the muscle insertion was transected at the facet joint. Gelpi retractors were placed to facilitate exposure. The locking plate was applied unilaterally on the right side of L1 and L2. Knowledge of the angles measured on CT for each individual vertebral column was used to guide implant insertion, with the surgeons taking into account an estimation error of 4°.[23] Because locking plates were used, bore holes for the screws were drilled perpendicular to the plate to facilitate locking of the screw heads. The two outermost screw holes on both ends of the plate were torqued at an angle of 5° toward ventral to achieve correct screw placement. Furthermore, the plate was contoured to assist in positioning around the facet joint (**Figure 6**); bending and adjustment of the plate on the vertebrae was verified visually. The plate was positioned such that the middle hole was located laterally on the facet joint; the second and fourth holes remained empty, and the first and fifth holes were seated on laminar bone (Figure 1).

An adjustable drill guide[f] was used to determine the point of exit of screws on the opposite side of the base of the dorsal spinous process. The previously measured insertion angle for drilling of the screw hole was used, and an attempt was made to position the screws close to the maximum angle without entering the vertebral canal. The plate was placed on the facet joint and moved ventrally until the cranial and caudal ends of

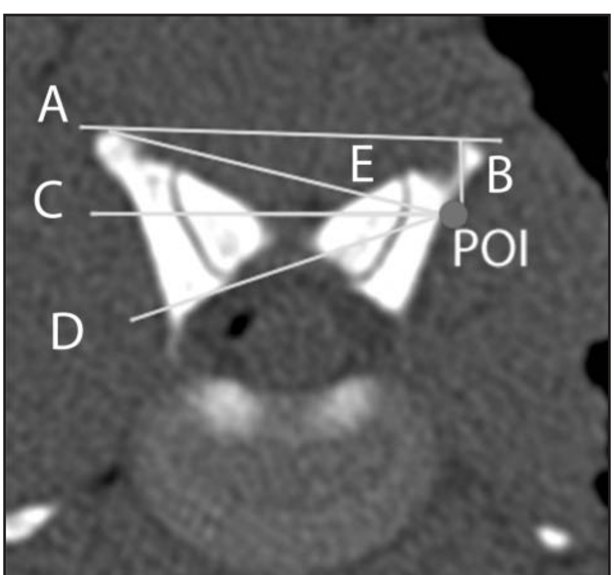

Figure 3—Preoperative CT image of the vertebral column of a canine cadaver. The POI for the facet screw (gray circle) is located at the lateral aspect of the facet joint on a horizontal line (line C) drawn 0.6 cm (line B) ventral to a horizontal line (line A) that passes through the dorsal rims of the facet. Minimum and maximum angles were measured relative to line C. The maximum angle is the angle between line C and a line (line D) drawn from the POI to the border of the vertebral canal. The minimum angle is the angle between line C and a line (line E) drawn from the POI to the dorsal border of the facet joint. Notice that multiple cortices are penetrated by a facet screw placed between the minimum and maximum angles.

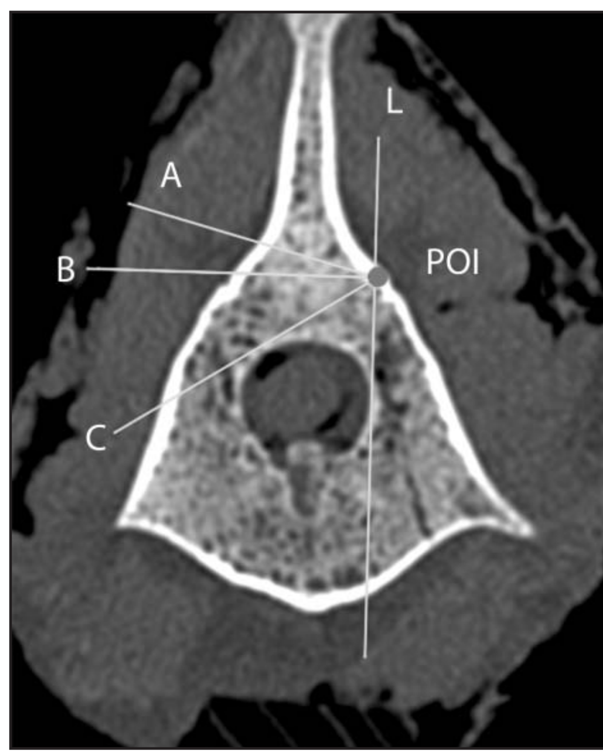

Figure 4—Preoperative CT image through the middle of L1 (measured in a sagittal plane from endplate to endplate) indicating the POI for the laminar screw (gray circle). This was defined as the most cranial part through a vertical line (line L) drawn at the lateral border of the vertebral canal where it intersects the outer cortex of the vertebra. Minimum and maximum angles were measured relative to a line (line B) perpendicular to line L and that bisected the POI. The minimum angle is the angle between line B and a line (line A) drawn through the POI and that includes 2 cortices of the lamina ventral to the base of the spinous process. The maximum angle is the angle between line B and a line (line C) drawn through the POI and that passes as close as possible to the vertebral canal. Minimum angle was 9.39°, and the maximum angle was 23.98°.

the ventral border of the plate were seated on the lateral part of the dorsal lamina. The dorsal border of the plate did not touch the lamina. The dorsal border of the plate at the facet joint was at the same height as the dorsal tip of the facet joint. Accordingly, the POI was related to the position of the plate. The POI for the laminar screw could be located during implantation by following 3 lines that originated from the accessory process and extended cranially, from the mammillary process and extended caudally, and from the caudal articular process and extended cranially. The point at which these lines intersected was the middle of the vertebra and represented the laminar insertion point (**Figure 7**).

Drilling was performed first for the cranial and caudal laminar screws, which was followed by drilling for the facet screw. Holes were drilled with a 2.4-mm drill bit for the 2 locking screws (3.0-mm locking screw[e]) and with a 2.0-mm drill bit for the standard facet screw (2.4-mm nonlocking screw[e]). Length of each screw was measured, and the self-tapping screws were inserted at the same angle as for the drilled holes.

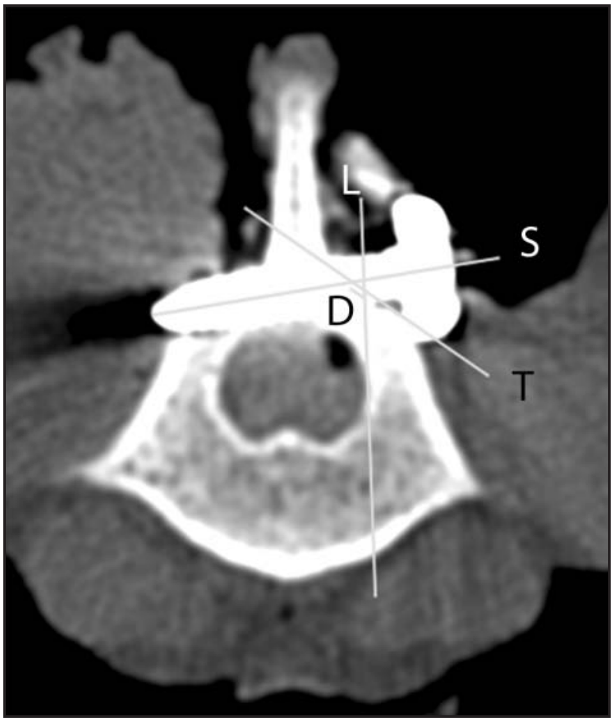

Figure 5—A CT image depicting the association between the preoperatively determined POI and the actual point at which the screw was inserted. The distance (line D) is measured from the center of the screw (line S) to the POI, which is found with line L along a tangential line (line T) representing the laminar ciscortex. The length of line D was 800 µm.

Figure 6—Photograph of the precontoured plate. Notice the slight ventral torque for the 2 lateral holes.

Data analysis—Descriptive analysis was performed by use of statistical software.[g] Minimum and maximum angles measured on preoperative images were recorded as mean ± SD. Ranges were also reported. Postoperative angles were evaluated with regard to the preoperative corridor (the value between the minimum and maximum preoperative angles) for each vertebral column.

Results

Preoperative CT measurements—Mean ± SD maximum and minimum insertion angles for L1 were 18 ± 4.0° (range, 12° to 25°) and –11 ± 4.4° (range, –7° to –21°), respectively (**Table 1**). Mean maximum and minimum insertion angles for L2 were 21 ± 5° (range, 9° to 26°) and –10 ± 3° (range, –8° to –16°), respectively. Mean maximum and minimum insertion angles of the facet screws were 24 ± 4° (range, 18° to 29°) and –12 ± 2° (range, –8° to –14°), respectively.

Postoperative CT measurements—Mean ± SD insertion angle for L1 was 7.9 ± 7.0° (range, –7° to

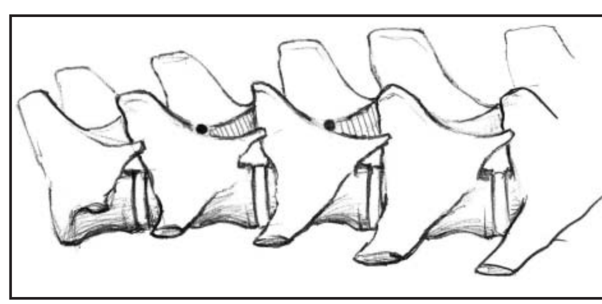

Figure 7—Illustration of a canine vertebral column. The area at which the mammillary process, accessory process, and caudal articular process merge on L1 and L2 (parallel lines) is indicated, and the location of their intersection on each vertebra is the POI (gray circle).

Table 1—Preoperative minimum and maximum angles for screw insertion and insertion angles measured after implantation for 24 screws inserted in the vertebral columns obtained from 8 canine cadavers.

		L1		L2		Facet joint		Measured postoperative angles (°)		
Variable	Body weight (kg)	Minimum angle (°)	Maximum angle (°)	Minimum angle (°)	Maximum angle (°)	Minimum angle (°)	Maximum angle (°)	L1*	L2	Facet
Mean ± SD	22.9 ± 5.25	–11 ± 4.4	18 ± 4.0	–10 ± 3.0	21 ± 5.0	–12 ± 2.0	24 ± 4.0	8 ± 7.0	11 ± 8.0	3 ± 11.0
Range	17 to 30	–21 to –7	12 to 25	–16 to –8	9 to 26	–14 to –8	18 to 29	–7 to 17	–2 to 24	–14 to 17

*The screw did not follow the drill hole and was not within the planned insertion corridor (value between the minimum and maximum preoperative angles) in 1 vertebra, which resulted in that screw penetrating the vertebral canal.

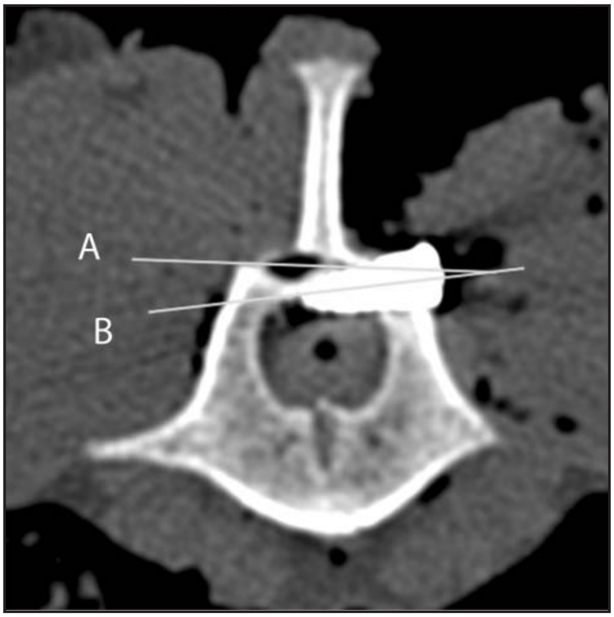

Figure 8—A CT image of a screw that penetrates the vertebral canal. The drill hole (line A) does not penetrate the vertebral canal and is dorsal to the tract created by insertion of the screw (line B).

17°). Two cortices were included with the laminar screws, and the screws were placed in the planned area of L1. Mean length of purchased bone was 9.9 ± 1.9 mm (range, 8 to 13 mm). Inadvertent insertion into the vertebral canal was detected in 1 screw inserted into L1 (**Figure 8**). In this case, the drill hole appeared to be at the correct angle but the self-tapping screw was inserted and traversed ventral to the drill hole, which created a new screw tract that penetrated the vertebral canal.

Mean ± SD insertion angle for L2 was 11 ± 8° (range, –2° to 24°). Two cortices were included with all the laminar screws, and the screws were placed dorsally in L2. Mean length of purchased bone was 14.5 ± 2.6 mm (range, 11 to 18 mm). The preoperatively measured angle of insertion was maintained in all cases for L2.

Mean ± SD insertion angle of the facet screw was 3.0 ± 11.0° (range, –14° to 17°; **Figure 9**). Mean number of cortices included for the facet screws was 6.4 ± 0.7 (range, 5 to 7), and none of the screws was placed dorsal to the facets or into the vertebral canal. Mean length of purchased bone was 13.8 ± 5.2 mm (range, 8 to 23 mm). The preoperatively measured insertion angle was maintained for all of the facet screws.

Implant assessment—Inadvertent insertion into the vertebral canal was detected for 1 of 24 (4%) screws; that screw was inserted outside the drill hole. The remaining inserted screws were dorsal to the vertebral canal. There was no breakage of cortices, and screws were satisfactorily placed with regard to position and bone purchase.

Mean measured deviation from POI and achieved position of the laminar screws was 0.80 mm for L1 and 1.75 mm for L2. Mean measured deviation for the facet screw was 0.85 mm (**Table 2**).

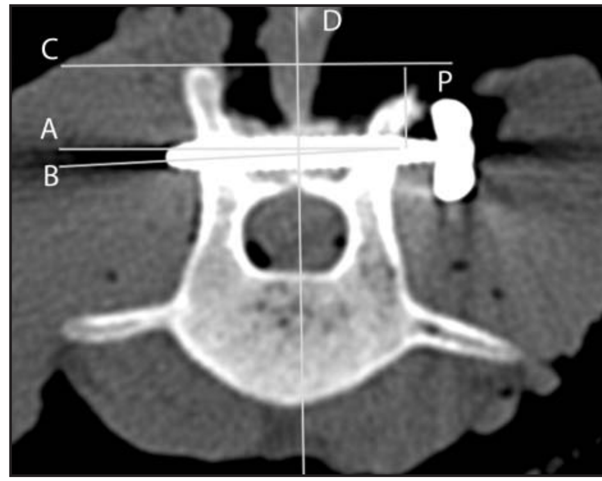

Figure 9—A CT image of measurement of the angle of the screw inserted through the facets of L1. A horizontal line (line C) passes through the dorsal rim of the facets. The angle between the line (line B) that passes through the middle of the screw and a horizontal line (line A) that is parallel to line C is the angle of insertion. For the measurements, a vertical line (line D) has been drawn to provide a better orientation and to ensure that line A and C are both perpendicular to line D. Angle of insertion is 2.97°. Line P represents the distance from the dorsal border of the facet joint to the center of the screw.

Table 2—Mean and range values for the association between the planned POI and the point at which a screw was inserted as determined by use of measurements obtained after implantation.

		Distance (mm)	
Structure	Direction of deviation	Mean	Range
L1	4 dorsal, 2 ventral, and 2 no deviation	0.80	0–1.60
L2	6 dorsal and 2 ventral	1.75	0.60–2.60
Facet joint	—	0.85	0.45–3.00

Direction of deviation (dorsal or ventral) is indicated for laminar screws; for screws with no deviation, the distance was 0 mm.
— = Not applicable.

Discussion

In the study reported here, the angles of insertion for the placement of screws into the lamina of L1 and L2 and the adjacent facet joint were evaluated to determine the optimum insertion angles for laminar vertebral stabilization in dogs. Defining these landmarks is important to ensure adequate stability of the implant and to avert damage to adjacent structures. Therefore, we determined a maximum angle, above which the vertebral canal would be penetrated, and a minimum angle, below which stability would be questionable.

Analysis of results of this study indicated that maintaining these angles was feasible. If a common insertion angle, calculated as the smallest angle for all specimens tested, is considered, some of the postoperative angles for screw insertion would not have maintained this guideline regarding damage to the vertebral canal. Steep angles were chosen on the basis of examination of preoperative CT images and because we were attempting to achieve an angle for the drill hole close to the measured maximum angle. Given the suggestion that in clinical patients, a surgeon would attempt to make a horizontal drill hole, we considered that the maximum angle was safe and could be easily achieved, which would avoid the need for preoperative CT for the determination of angles. A horizontal drill hole would provide enough bone purchase and can be considered safe, compared with the minimum angle calculated in the present study. Nonetheless, use of an adjustable drill guide is recommended to drill at precise planned angles and estimate the point of exit.

In the present study, the main implant complication was insertion of a screw into the vertebral canal. Other major structures at risk of damage during vertebral body plating, such as blood vessels or, in the case of stabilization of the thoracic vertebrae, the thorax, are not within the range of the drill corridor for laminar plating.[13] Because the drill angles were based on the estimation of the surgeon, a certain margin of error must be considered, and an additional safety margin of ± 4° to allow operator error in estimation has been suggested.[24] Results of the present study indicated a sufficiently wide margin (ie, corridor) for safe drilling because none of the drill holes led to penetration of the vertebral canal. In addition, none of the screws was placed too dorsally, which would have resulted in insufficient bony purchase. However, one of the screws was placed outside of the drill hole and penetrated the vertebral canal, which emphasizes the potential danger with the use of self-tapping screws and underscores the importance of maintaining the drill holes during insertion of these screws.

The angle recommended for vertebral body fixation of lumbar vertebrae ranges from 50° to 60° in relation to a vertical axis.[20,23,a] This is easy to achieve because no soft tissue structures obstruct the drill angle. The almost horizontal placement necessary for laminar fixation can be more difficult because the lateral paraspinal musculature is located in the line of drilling. However, the use of a drill guide was found helpful to facilitate correct placement of the screw. A small-incision approach through the muscles could also be considered to facilitate drilling. In contrast, placement of a dorsal plate requires a relatively superficial approach with little soft tissue dissection, compared with that necessary for vertebral body plates.

In bones with thick cortices, monocortical insertion of locking screws may be acceptable, although bicortical insertion is recommended when a cortex is weak, such as in osteoporotic bones in humans.[25] We could confirm the purchase of 2 cortices for the laminar screws and between 5 and 7 cortices for the facet screws, which suggested good stability of the implant. Purchase of the cranial cortex is believed to provide a 25% increase in pullout strength of transpedicular vertebral screws used for vertebral alignment, stabilization, or fusion in humans.[26] Compared with vertebral fixation, the number of cortices with laminar screws that were able to obtain purchase was high because it can be dangerous to penetrate the transcortex during vertebral body stabilization. Indeed, the distance from the transcortex of the vertebral body to the caudal vena cava and the aorta can be as little as 3.2 mm in the lumbar region,[20] and inadvertent drilling through the far cortex must be confined to a short distance. The risk of damage to underlying structures is even higher for thoracic vertebrae.[22] For the facet screws, biomechanical testing in the canine vertebral column should be performed to confirm the contribution of the facet screw to the implant stability, although satisfactory biomechanical stability of transfacet screws has been reported in humans.[27,28]

The locking plates used in the present study have been used in a number of veterinary applications, including ventral stabilization of the cervical vertebrae in dogs and cats.[29–31] To ensure screws remain locked in a plate, the screws must be applied perpendicular to that plate. Bending of plates determines most of the insertion angle; thus, precontouring of plates is extremely important. We found that the ends of the plate must be torqued approximately 5° in a ventral direction to direct the screw toward the insertion angle and to affix the implant close to the bone. The process of plate bending requires some experience, and a considerable degree of bending is required to fit the plate around the facet joint (Figure 6).

The insertion corridors in the study reported here were relevant only to L1 and L2, and additional studies are required to determine insertion corridors for other areas of the vertebral column. It may be more difficult to apply plates to the thoracic vertebrae because of the deeply located, variably shaped articular surfaces, lack of mammillary processes cranial to T11, and short vertebral bodies. This may make it challenging to apply plates, especially in small dogs, but it also is challenging to perform vertebral body plating. The range of the vertebral column in which plating techniques can be used needs to be determined, but in our experience, preliminary clinical results are promising for the caudal portion of the thoracic vertebrae as well as the caudal portion of the lumbar region.

One main consideration was the association between the POI used to measure the preoperative angle and the point at which the screw was actually inserted. If these points do not correspond, the measured angles are of no use. This appears to be even more important because the anatomic location of the POI is difficult to describe. The point for the laminar screw in L1 and the facet screw corresponded with a mean difference of 0.80 and 0.85 mm between the tested specimen, respectively, which was well within the limits for the POI. The position of the screw for L2 differed with a mean of 1.75 mm, but the authors still considered this to be within acceptable limits. Furthermore, the screws could be placed satisfactorily even though the measured angle was not 100% accurate. The difference in the association may have been related to the fact that the implantation proceeded by insertion of laminar screws from cranial to caudal, so it was sometimes difficult to ensure the position of the plate coincided with the cranial and caudal laminar points of insertion because the caudal articular process interfered with the plate and necessitated a more dorsal position for the plate. This may explain the greater deviation in the median association of the screw in L2. However, the results still indicated a satisfactory position in these segments and a similar range of angles for the screw insertions.

Finally, the mean angles were calculated from only a small number of vertebral columns obtained from dogs with a limited range of body weights. To determine more specific angles, a larger number of cadavers of various sizes should be examined.

Safe insertion angles for the facet joint and lamina of L1 and L2 for laminar stabilization were confirmed in the study reported here. If appropriate angles are known, then screws can be placed safely. The intraoperative feasibility of maintaining the measured angles was confirmed by evaluation of CT images obtained during implant placement. Purchase into several cortices, especially for the facet screws, was verified. Superior implant stability for this technique, compared with that for other stabilization techniques, has been reported in an in vitro biomechanical study.[32]

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