

# Feasibility and accuracy of intraosseous endoscopy for inspection of thoracolumbar and lumbar pedicle drill tracts in a canine large-breed cadaveric model

Ronan A. Mullins, MVB, DVMS, DECVS, PGDipUTL<sup>1\*</sup>; Cristina Ortega, DVM, PgCertSAS<sup>1</sup>;  
Jason Bleedorn, DVM, MS, DACVS<sup>2</sup>; Marie Pauline Maurin, DVM, DVMS, DECVS, PGDipUTL<sup>1</sup>;  
Seamus Hoey, MVB, PhD, DECVDI, DACVR, DI, EDI<sup>3</sup>; Jorge Espinel Ruperez, LV, DVMS, DECVS, PhD<sup>4</sup>;  
Karl H. Kraus, DVM, MS, DACVS<sup>5</sup>; Scott Hetzel, MS<sup>6</sup>; Julien Guevar, DVM, MVM, DECVN<sup>7-9</sup>

<sup>1</sup>Department of Small Animal Surgery, Section of Small Animal Clinical Studies, University College Dublin, Dublin, Ireland

<sup>2</sup>Department of Clinical Sciences, Colorado State University, Fort Collins, CO

<sup>3</sup>Equine Clinical Studies, Section of Diagnostic Imaging and Anesthesia, School of Veterinary Medicine, University College Dublin, Dublin, Ireland

<sup>4</sup>School of Veterinary and Life Sciences, College of Veterinary Medicine, Murdoch University, Murdoch, Western Australia, Australia

<sup>5</sup>Department of Clinical Sciences, College of Veterinary Medicine, Iowa State University, Ames, IA

<sup>6</sup>Department of Biostatistics and Medical Informatics, School of Medicine and Public Health, University of Wisconsin-Madison, Madison, WI

<sup>7</sup>AniCura Tierklinik Thun, Thun, Switzerland

<sup>8</sup>Vetelys, Vernier, Switzerland

<sup>9</sup>Division of Surgery, Department of Clinical Sciences, Vetsuisse Faculty, University of Bern, Bern, Switzerland

\*Corresponding author: Dr. Mullins (ronan.mullins@ucd.ie)

## OBJECTIVE

To evaluate the feasibility of endoscopic inspection of thoracolumbar and lumbar pedicle tracts in a canine large-breed model and its accuracy for the detection of breached versus nonbreached tracts.

## ANIMALS

2 greyhound cadavers.

## METHODS

CT scans of 2 greyhound cadavers from the sixth thoracic vertebra to the sacrum were obtained. Fifty-six pedicles were randomized to have drill tracts with different modified Zdichavsky grades (nonbreached, partial/full medial breach, or partial/full lateral breach) using 3-D-printed guides. Endoscopy was performed on a single occasion from October 9 to 10, 2023, using a 1.9-mm 0-degree needle arthroscope in a randomized blinded fashion. The grading of drill tracts was performed on postoperative CT. Specificity, sensitivity, positive and negative predictive values, and time to assign endoscopic grade were investigated.

## RESULTS

Postoperative CT confirmed 43 nonbreached tracts, 7 medial breaches (partial/full), and 5 lateral breaches (partial/full). One tract was excluded because of guide misplacement. Intraosseous endoscopy was successfully performed in the remaining 55 drill tracts. Sensitivity to detect medial and lateral breaches was 71.4% and 60.0%. Negative predictive value was 93.1%. Specificity was 94.2%. Positive predictive value for detection of medial and lateral breaches was 83.3% and 54.5%. Median (range) time to assign an endoscopic grade was 118 (30 to 486) seconds.

## CLINICAL RELEVANCE

Intraosseous endoscopy of pedicle drill tracts may be a useful adjunct technique during pedicle screw/pin placement in dogs.

**Keywords:** dog, intraosseous endoscopy, pedicle, spinal, Zdichavsky

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Stabilization of the canine vertebral column is technically challenging, and improper implant placement can be associated with significant patient morbidity and even mortality.<sup>1</sup> Several techniques have been used to guide the insertion of pins or

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screws into the canine thoracolumbar and lumbar vertebrae, including the use of 3-D-printed patient-specific drill guides (3DPGs),<sup>2-8</sup> fluoroscopy,<sup>9,10</sup> a free-hand technique based on preoperatively calculated safe corridors,<sup>11</sup> and a modification of the free-hand technique known as the pedicle-probing technique.<sup>12</sup> Although the use of 3DPGs has become increasingly popular in veterinary spine surgery and is associated with a very high rate of accuracy,<sup>2-6</sup> the hardware and software required to produce such guides are not universally available, and external sourcing of such guides can be associated with greater cost and treatment delays.<sup>13</sup> Unguided freehand instrumentation for the canine thoracolumbar and lumbar vertebral column remains commonplace in veterinary spine surgery, and there is a need for clinically practical techniques to assist surgeons in achieving safe, accurate, and consistent implant orientation.

Radcliff et al<sup>14</sup> demonstrated the feasibility of endoscopic inspection of pedicle drill tracts in an experimental live porcine model and its ability to successfully identify iatrogenic medial, lateral, and anterior lumbar breaches. No specialized pumps or pressure bags were required, with saline irrigation allowed to flow at gravity pressure.<sup>14</sup> Frank and Chamberland<sup>15</sup> described the use of a 1.2-mm endoscope adapted to fit within a hollow pedicle probe, with irrigation provided via a separate channel within the endoscope. This device was used to probe 36 sawbones and 22 human cadaveric thoracolumbar pedicles; however, a limitation of that study is that no breaches were created in the cadaveric specimens, and therefore its ability to detect breach was not evaluated. In another live ovine experimental study,<sup>16</sup> intraosseous endoscopy of lumbar pedicle tracts was performed using a 3.0-mm 30-degree arthroscope, and all 11 pedicle breaches were successfully identified.

We believe that endoscopic inspection of pedicle drill tracts could have substantial scope in veterinary spine surgery, including but not limited to fracture stabilization, lumbosacral stabilization, and spinal deformity correction. However, to our knowledge, no studies have investigated the feasibility of this technique in the canine thoracolumbar and lumbar spine and its ability to identify breached versus nonbreached pedicle tracts. Therefore, our objective was to investigate the feasibility of an endoscopic technique for inspection of pedicle drill tracts in a canine large-breed cadaveric model. We evaluated its accuracy for the detection of nonbreached drill tracts as well as those with medial or lateral breaches. We hypothesized that endoscopic inspection of pedicle drill tracts would be (1) technically feasible and (2) associated with a high (defined as > 90.0%) rate of reliability for the detection of nonbreached drill tracts and those with medial or lateral violations.

## Methods

### Sample population

Two skeletally mature greyhound cadavers euthanized for reasons unrelated to the study were

included. Ethical approval was obtained from the primary author's institution (AREC-E-23-07-Mullins). Cadavers were stored at -20°C and defrosted 48 hours prior to preoperative CT.

### Preoperative CT

Cadavers were positioned in sternal recumbency, with the thoracic limbs extended cranially and the pelvic limbs flexed with the feet on either side of the abdomen. A 16-slice helical CT scanner (SOMATOM Scope; Siemens) was used in the study. A small-bone protocol was used, and each cadaver was scanned from the sixth thoracic vertebra (T6) to the sacrum at 130 kVp and 220 mAs, using a 0.75-mm scanned slice thickness reconstructed in high-frequency iterative reconstruction algorithm images. DICOM images were exported into medical image-viewing software (Horosproject.org). After image acquisition, cadavers were refrozen until 3DPGs were designed and printed.

### Design and creation of 3-D-printed drill guides

DICOM images were imported into 3-D-planning software (Mimics v21, 3-Matic v15; Materialise), and virtual models of 3DPGs were designed by a board-certified neurologist (JG). All guides were single non-bridged bilateral guides and designed as previously described,<sup>12</sup> with a 2.5-mm internal diameter that matched the pilot hole size for a 3.2/2.4-mm positive profile pin (Interface pins; IMEX). Guides were printed by one author (JB) using a stereolithography printer (Surgical Guide resin, Form 3B; Formlabs) and biocompatible resin with 25-μM XY resolution (horizontal resolution) and 100-μM (0.1 mm) layer height (vertical resolution). 3DPGs were designed to create 2 drill tracts per vertebra, 1 left and 1 right, from T7 through the seventh lumbar vertebra, equating to a total of 28 drill tracts per cadaver (56 drill tracts in total). The modified Zdichavsky classification described by Elford et al<sup>3</sup> was used in this study. Three guides were designed to create a deliberate grade 2a breach (partial medial violation), another 3 to create a grade 2b breach (full medial violation), a further 3 to create a grade 3a breach (partial lateral violation), and a final 3 to create a grade 3b breach (full lateral violation).<sup>3,12,17</sup> The remaining 44 guides were designed to create no breach (grade 1 modified Zdichavsky).<sup>3,12,17</sup> The allocation of breaches to individual vertebrae as well as the side of the breach (left vs right) were randomized. Information regarding the number and location of deliberate breaches was not known to the surgeons grading the drill tracts on endoscopy (RAM and MPM).

### Creation of pedicle drill tracts

Cadavers were placed in sternal recumbency with the thoracic limbs extended cranially and the pelvic limbs in a neutral position. A routine dorsal approach to the thoracolumbar and lumbar vertebral column was performed bilaterally from T6 to the seventh lumbar vertebra by 2 authors (RAM and CO). Epaxial musculature was reflected bilaterally without disruption of supraspinous or interspinous

ligaments. Soft tissues were meticulously removed over areas of bone to ensure complete and precise contact of 3DPGs. 3DPGs were held firmly in position by hand, and a 2.5-mm drill bit was used to create a pilot through the guide tube. All drill tracts were created by a first-year surgery resident (CO), with no other surgeon present in the room while drilling.

### Assessment of pedicle wall integrity

Cadavers were draped in a simulated surgical environment. Intraosseous endoscopy and assessment of pedicle wall integrity were performed within approximately 2 minutes of drilling to replicate the clinical situation as much as possible. A 1.9-mm 0-degree needle arthroscope (NanoScope; Arthrex) (Figure 1) within its 2.4-mm outer diameter cannula was carefully inserted by one author (CO) into each drill tract. Saline was allowed to flow at gravity pressure, with no specialized pumps or pressure bags used. To help passage of the scope, a small Kirschner wire was often passed into the pilot hole to show its trajectory. Each pedicle was graded separately on a single occasion by 2 European College of Veterinary Surgeons board-certified surgeons (RAM and MPM) according to the modified Zdichavsky classification described by Elford et al.<sup>3,12</sup> Endoscopic inspection of each drill tract was performed in a randomized fashion (www.random.org) determined a priori. Neither surgeon had prior experience with intraosseous endoscopy, but both had significant experience with spinal

surgery in small animals. Both surgeons were familiar with the modified Zdichavsky classification and had reviewed the Radcliff et al<sup>14</sup> publication prior to the study. When assessing the integrity of each drill tract, surgeons stood behind a nontransparent screen and were only permitted to view the live video output on the NanoScope imaging console and gave instruction to the operator (CO) to advance and retract the scope as necessary in order to determine the grade. This setup was done to prevent the surgeon from seeing the direction of the scope or the location of the pilot hole, both of which could bias the decision regarding the grade. The first surgeon to assess a drill tract was alternated. The scope was passed in a standardized way such that up on the screen was always pointed medially and down pointed laterally to allow orientation for the surgeon. A video recording of each pedicle tract was saved on the imaging console. The time taken to perform each endoscopy was recorded and was defined as the time, in seconds, from insertion of the endoscope into the drill tract until a grade was decided by the surgeon.

### Postoperative CT

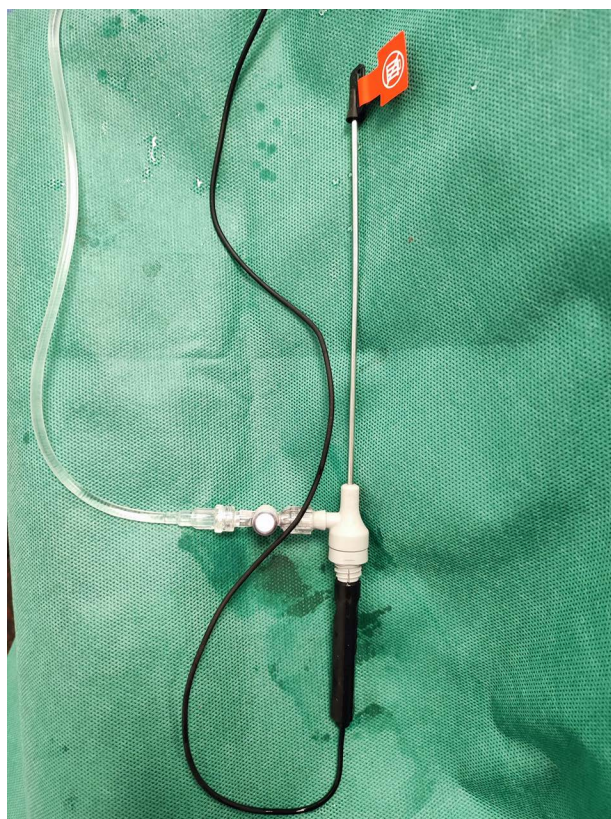
Repeat CT examinations were obtained from T6 to the sacrum with cadavers in the same sternal position using the previously described preoperative protocol and assessed in Horos. Using multiplanar reconstruction, dorsal and transverse plane axes were aligned with each pin tract trajectory, and grading was performed on transverse plane images. Grading was performed on a single occasion by a board-certified neurologist (JG) using the modified Zdichavsky classification described by Elford et al.<sup>3,12</sup>

### Statistical analysis, evaluation of accuracy, and feasibility

The normality of continuous data was assessed using the Shapiro-Wilk test. Continuous data are summarized as median (range). Specificity (defined as the likelihood that a grade 1 pedicle drill tract was correctly identified) and sensitivity (defined as the likelihood that a medial [grade 2] or lateral [grade 3] breach/violation was correctly identified) were evaluated and compared between surgeons using the Fisher exact test. Positive and negative predictive values were also calculated. Feasibility was dichotomously defined as the ability to complete the endoscopic inspection of pedicle drill tracts and assign a modified Zdichavsky grade. The time taken to assign a modified Zdichavsky grade was compared between surgeons for the thoracic spine, lumbar spine, and overall using the Wilcoxon signed-rank test. For all comparisons,  $P < .05$  was considered significant. All statistical tests were performed using SPSS Statistics, version 27 (IBM Corp).

### Results

Two greyhound cadavers were included, 1 male and 1 female. Their bodyweights were 31.5 and 24.5 kg, respectively. Postoperative CT identified



**Figure 1**—The 1.9-mm 0-degree needle arthroscope used in this study within its 2.4-mm outer cannula.



43 grade 1 drill tracts, 7 medial breaches, and 5 lateral breaches. The pedicle drill tract on the right side of T7 in cadaver 2 had to be excluded (intended grade 1 tract) because of guide misplacement and incorrect drilling, meaning that 55 drill tracts were included in the analysis.

## Feasibility

Endoscopic inspection was technically feasible in all 55 drill tracts. There was no difference in the ability to pass the scope in the thoracic versus lumbar vertebral column. Placement of a Kirschner wire into the pilot hole helped passage of the scope by showing the correct trajectory. Passage of the arthroscope within the pilot hole was relatively tight and was performed slowly, with minor adjustments in direction based on the live video output on the NanoScope imaging console. Immediately after drilling, blood and bone debris mildly and very briefly impaired visualization of the drill tracts but subsided with passage of the scope and saline irrigation. On occasion, bone debris would obscure the tip of the scope, resulting in the need for the scope to be removed, cleaned and reinserted. The same arthroscope was used for all drill tracts, and no gross injury to the scope was identified at the completion of the study. Subjectively, surgeons found it easier to

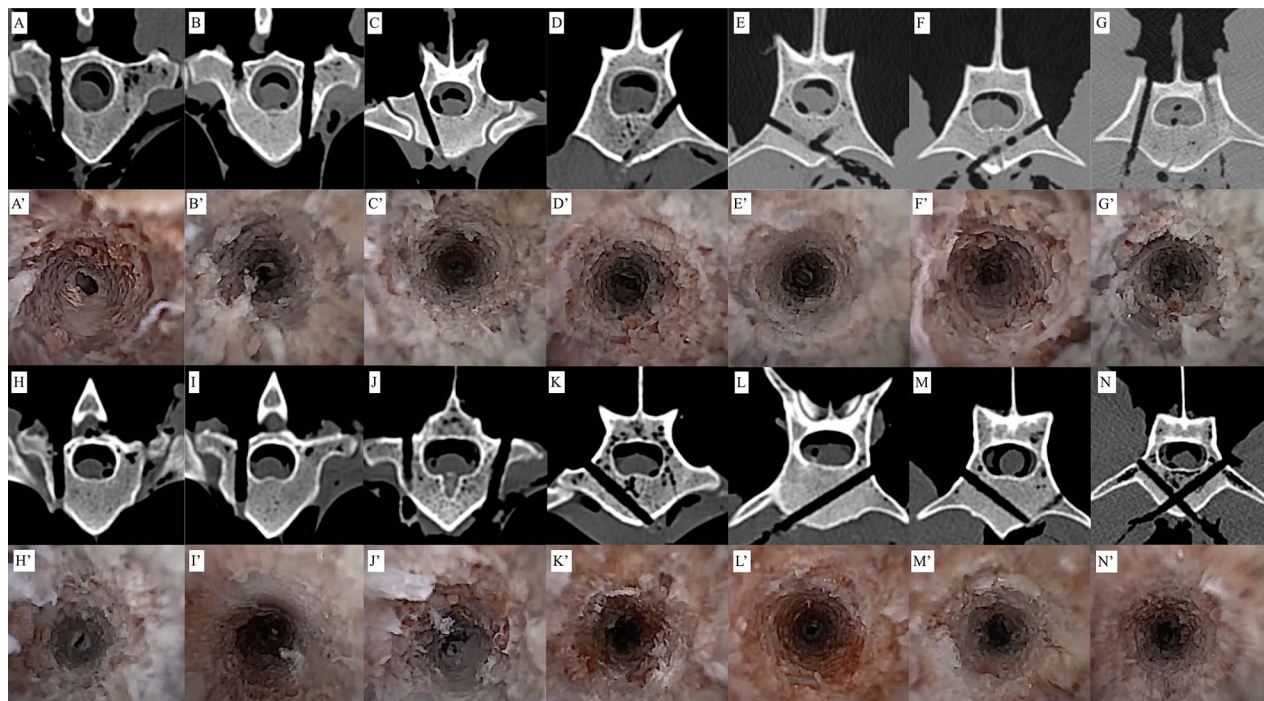
assign a grade in the lumbar spine, possibly because the drill tracts were often longer and surrounded by a larger volume of cancellous bone compared with those in the thoracic spine.

## Accuracy

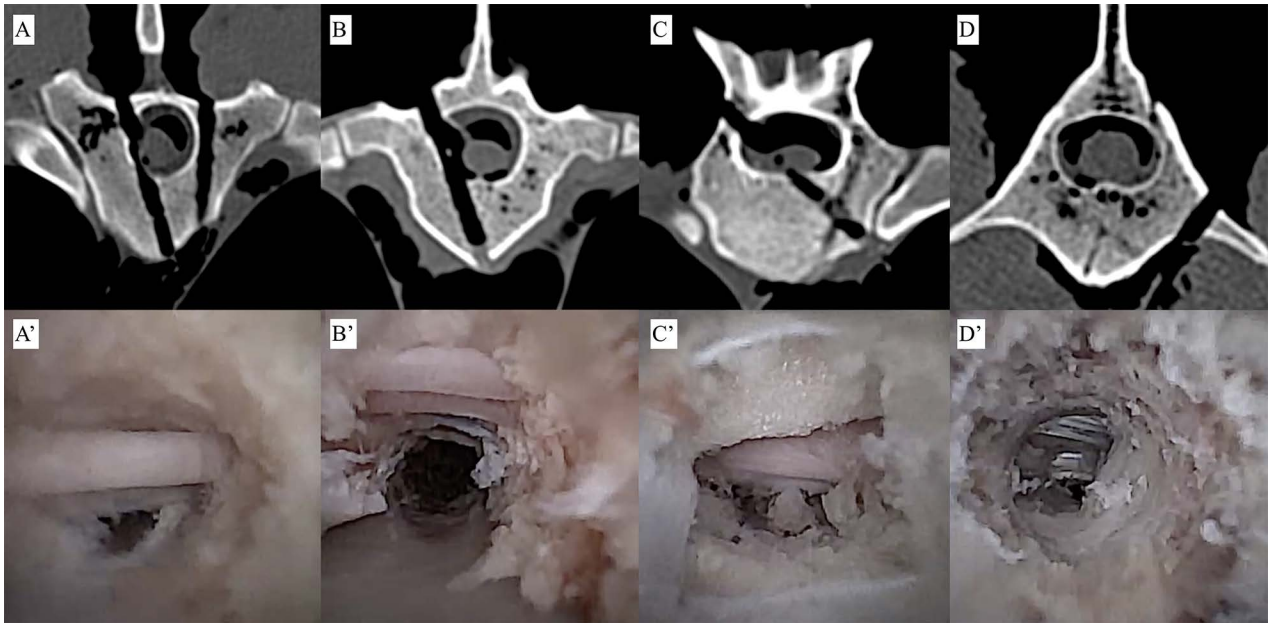
Surgeons correctly identified 94.2% of intact drill tracts (**Figure 2**), 71.4% of medial breaches (**Figure 3**), and 60.0% of lateral breaches (**Figure 3**) (**Table 1**). Overall (both surgeons) specificity was 94.2%. Overall positive predictive value (PPV) for the detection of a medial and lateral breach was 83.3% and 54.5%, respectively. Overall sensitivity to detect a medial breach (grade 2) was 71.4%. Overall sensitivity to detect a lateral breach (grade 3) was 60.0%. Overall negative predictive value was 93.1% (**Table 2**). No significant differences in these comparisons were identified between surgeons.

## Drill tract appearance based on the modified Zdichavsky classification

A grade 1 drill tract was characterized by a relatively long cylindrical tract with the majority of its inner circumference lined with cancellous bone (**Figure 2**), a distinct grey-white ring of cortical bone at its most ventral aspect (representing the ventral cortex) and oriented approximately perpendicular



**Figure 2**—Transverse plane multiplanar reconstruction (MPR) computed tomographic (bone window; window width and length in the region of 2,500 and 500, respectively; 0.75-mm slice thickness) and corresponding intraosseous endoscopic images of a selection of correctly identified grade 1 modified Zdichavsky drill tracts. Images A–G are from cadaver 1, whereas images H–N are from cadaver 2. Extending from left to right across the upper half is the right side (R) of the eighth thoracic vertebra (T8) (A and A'), the left side (L) of T10 (B and B'), T12R (C and C'), the first lumbar vertebra (L1)–L (D and D'), L3R (E and E'), L5L (F and F'), and L7R (G and G'). Extending from left to right across the lower half is T8R (H and H'), T9R (I and I'), T11L (J and J'), T13R (K and K'), L2L (L and L'), L4R (M and M'), and L6L (N and N'). The left side of all CT images is the right side of dog. The upper half of endoscopic images represents the medial wall of the pedicle drill tract, and the lower half represents the lateral wall.



**Figure 3**—Transverse plane MPR computed tomographic (bone window; window width and length in the region of 2,500 and 500, respectively; 0.75-mm slice thickness) and corresponding intraosseous endoscopic images of 3 correctly identified grade 2b modified Zdichavsky drill tracts (A–C and A'–C') and 1 correctly identified grade 3b modified Zdichavsky drill tract (D and D'). Images A and B are from cadaver 1, whereas images C and D are from cadaver 2. Extending from left to right is T7R, T11R, T12R, and L5L. The left side of all CT images is the right side of dog. The upper half of endoscopic images represents the medial wall of the pedicle drill tract, and the lower half represents the lateral wall. Note the medial edge of the ventral longitudinal ligament toward the top of the videoendoscopic image in D'.

**Table 1**—Proportion of correctly identified drill tracts in the thoracic and lumbar spine overall and for individual surgeons.

| Modified Zdichavsky grade | Surgeon 1   | Surgeon 2   | Overall         |
|---------------------------|---|---|-----------------|
| Grade 1                   | <ul style="list-style-type: none"> <li>• 42/43 (97.7%) correctly identified</li> <li>• 26/27 (96.3%) thoracic pedicles</li> <li>• 1 incorrectly assigned grade 3b</li> <li>• 28/28 (100.0%) lumbar pedicles</li> </ul>                              | <ul style="list-style-type: none"> <li>• 39/43 (90.7%) correctly identified</li> <li>• 23/27 (85.2%) thoracic pedicles</li> <li>• 3 incorrectly assigned grade 3a and 1 grade 3b</li> <li>• 28/28 (100.0%) lumbar pedicles</li> </ul> | • 81/86 (94.2%) |
| Grade 2a                  | <ul style="list-style-type: none"> <li>• 0/2 (0.0%) correctly identified</li> <li>• 2 incorrectly assigned grade 1</li> </ul>   | <ul style="list-style-type: none"> <li>• 1/2 (50.0%) correctly identified</li> <li>• 1 incorrectly assigned grade 1</li> </ul>  | • 1/4 (25.0%)   |
| Grade 2b                  | <ul style="list-style-type: none"> <li>• 3/5 (60.0%) correctly identified</li> <li>• 2 incorrectly assigned grade 2a</li> </ul>   | <ul style="list-style-type: none"> <li>• 4/5 (80.0%) correctly identified</li> <li>• 1 incorrectly assigned grade 1</li> </ul>  | • 7/10 (70.0%)  |
| Combined grade 2          | <ul style="list-style-type: none"> <li>• 5/7 (71.4%)</li> <li>• 3/3 (100.0%) thoracic pedicles</li> <li>• 2/4 (50.0%) lumbar pedicles</li> <li>• 2 incorrectly assigned grade 1</li> </ul>  | <ul style="list-style-type: none"> <li>• 5/7 (71.4%)</li> <li>• 3/3 (100.0%) thoracic pedicles</li> <li>• 2/4 (50.0%) lumbar pedicles</li> <li>• 2 incorrectly assigned grade 1</li> </ul>  | • 10/14 (71.4%) |
| Grade 3a                  | <ul style="list-style-type: none"> <li>• 0/2 (0.0%) correctly identified</li> <li>• 1 incorrectly assigned grade 1 and 1 grade 2a</li> </ul>  | <ul style="list-style-type: none"> <li>• 1/2 (50.0%) correctly identified</li> <li>• 1 incorrectly assigned grade 1</li> </ul>  | • 1/4 (25.0%)   |
| Grade 3b                  | <ul style="list-style-type: none"> <li>• 2/3 (66.7%) correctly identified</li> <li>• 1 incorrectly assigned grade 2a</li> </ul>   | <ul style="list-style-type: none"> <li>• 2/3 (66.7%) correctly identified</li> <li>• 1 incorrectly assigned grade 3a</li> </ul>   | • 4/6 (66.7%)   |
| Combined grade 3          | <ul style="list-style-type: none"> <li>• 2/5 (40.0%)</li> <li>• 1/2 (50.0%) thoracic pedicles</li> <li>• 1 incorrectly assigned grade 2a</li> <li>• 1/3 (33.3%) lumbar pedicles</li> <li>• 1 incorrectly assigned grade 1 and 1 grade 2a</li> </ul> | <ul style="list-style-type: none"> <li>• 4/5 (80.0%)</li> <li>• 2/2 (100.0%) thoracic pedicles</li> <li>• 2/3 (66.7%) lumbar pedicles</li> <li>• 1 incorrectly assigned grade 1</li> </ul>  | • 6/10 (60.0%)  |

to the tract, and typically the presence of a more ventrally located white ventral longitudinal ligament. Areas of grade 1 drill tracts that abutted the medial or lateral cortex but without breach were

characterized by focal loss of cancellous bone with exposure of grey-white cortical bone but without any bone defect. Grade 2a breaches were characterized by focal loss of cancellous bone (Figure 3) with

**Table 2**—Specificity, sensitivity, and positive and negative predicative values, with corresponding 95% confidence intervals, overall and for individual surgeons.

|  | Surgeon 1          | Surgeon 2          | Average            | P value (surgeon 1 vs 2) |
|--|--------------------|--------------------|--------------------|--------------------------|
| Specificity  | 97.7% (86.2–99.9%) | 90.7% (76.9–97.0%) | 94.2% (81.4–98.7%) | $P = .3600^a$            |
| PPV for a medial breach                                      | 71.4% (30.3–94.9%) | 100.0% (46.3–100%) | 83.3% (36.5–99.1%) | $P = .4697^a$            |
| PPV for a lateral breach                                     | 66.7% (12.5–98.2%) | 50.0% (21.5–78.5%) | 54.5% (17.9–87.1%) | $P > .9999^a$            |
| Sensitivity to detect presence of a medial breach (grade 2)  | 71.4% (30.3–94.9%) | 71.4% (30.3–94.9%) | 71.4% (30.3–94.9%) | $P > .9999^a$            |
| Sensitivity to detect presence of a lateral breach (grade 3) | 40.0% (7.3–83.0%)  | 80.0% (29.9–98.9%) | 60.0% (17.0–92.7%) | $P = .5238^a$            |
| NPV  | 93.3% (80.7–98.3%) | 92.9% (79.4–98.1%) | 93.1% (80.1–98.2%) | $P > .9999^a$            |

NPV = Negative predictive value. PPV = Positive predictive value.

<sup>a</sup>Fisher exact test.

exposure and disruption/penetration of grey-white medial cortical bone. Grade 2b breaches were characterized by the presence of larger medial cortical bone defects with exposure of neural tissue (spinal cord, nerve roots) and epidural fat (Figure 3). In contrast to a grade 2a partial medial breach, the lateral aspect of the drill tract at the level of the breach is lined by grey-white cortical bone (representing the interior of the vertebral canal) and not cancellous bone. Breach of the white dorsal longitudinal ligament on the ventral floor of the vertebral canal may also be observed. Passage of the scope through this ligamentous breach reveals a second tract representing the ventral continuation of the drill tract extending through the vertebral body. Grade 3a breaches were characterized by the presence of relatively short drill tracts and a ventral ring of cortical bone oriented somewhat oblique to the drill tract, with the medial part extending more ventral and the lateral part more dorsal. Finally, grade 3b breaches were characterized by the presence of short drill tracts, with a ventral cortex oriented approximately perpendicular to the tract and, depending on the lateral extent of the tract, the presence or absence of a white ventral longitudinal ligament (Figure 3).

### Time taken to assign a modified Zdichavsky grade on endoscopy

The median (range) overall time taken to assign a modified Zdichavsky grade was 118 (30 to 486) seconds: 154 (49 to 486) seconds for surgeon A and 98 (30 to 356) seconds for surgeon B ( $P < .00001$ ). For the thoracic spine, the median (range) time taken to assign a modified Zdichavsky grade was 177 (66 to 486) seconds for surgeon 1 and 98 (30 to 258) seconds for surgeon 2 ( $P < .00001$ ). For the lumbar spine, the median (range) time taken to assign a modified Zdichavsky grade was 141 (49 to 425) seconds for surgeon 1 and 96 (40 to 356) seconds for surgeon 2 ( $P = .00398$ ). The median (range) time taken by surgeon 1 to assign a modified Zdichavsky grade in the thoracic spine was not significantly different to that in the lumbar spine ( $P = .42372$ ). Similarly, the median (range) time taken by surgeon 2 in the thoracic spine was not significantly different to that in the lumbar spine ( $P = .56192$ ).

## Discussion

The main findings of this study are that endoscopic inspection of pedicle drill tracts was (1) possible to perform in all tracts and (2) associated with excellent specificity (94.2%) (defined as the likelihood that a grade 1 pedicle drill tract was correctly identified), fair sensitivity (71.4%) (defined as the likelihood that a breach/violation was correctly identified) for the detection of grade 2 (medial) breaches, and poor sensitivity (60.0%) for the detection of grade 3 (lateral breaches). Therefore, we accept our first hypothesis but must reject our second hypothesis.

Our first hypothesis was that endoscopic inspection of pedicle drill tracts would be technically feasible in a large-breed canine model. This was based on the results of 3 previous studies in which intraosseous endoscopy of porcine, ovine, and human pedicle tracts was successfully performed.<sup>14–16</sup> In a study by Radcliff et al,<sup>14</sup> intraosseous endoscopy of 8 lumbar pedicles was successfully carried out in an 82-kg adult pig using a 0-degree and 30-degree arthroscope. Stauber and Bassett<sup>16</sup> described successful endoscopic examination of lumbar pedicle drill tracts in 3 adult sheep, whereas Frank and Chamberland<sup>15</sup> reported successful cannulation of 22 pedicle tracts in 2 human cadaveric specimens. An important difference between the vertebral specimens used in previous studies<sup>14,16</sup> and those used in our study is the size of the vertebral drill tracts, and therefore the feasibility of intraosseous endoscopy remained unknown in the canine spine. For instance, in the study by Stauber and Bassett,<sup>16</sup> 5-mm pedicle drill tracts were created to accommodate a 3-mm scope within a 4.25-mm diameter cannula, whereas in the study by Radcliff et al,<sup>14</sup> although the specific size of the drill tracts is not stated, they were large enough to accommodate a 3-mm endoscope in combination with a ball-tipped probe. The size of the arthroscopes used in previous studies varied from 1.2 mm to 3 mm.<sup>14–16</sup> A 1.9-mm 0-degree needle arthroscope was used in our study. This scope, within its 2.4-mm diagnostic sheath, passed relatively easily within the 2.5-mm pilot hole required for placement of a 3.2/2.4-mm positive profile pin. Two studies<sup>14,16</sup> describe the use of a 30-degree arthroscope, with investigators in one study<sup>14</sup> describing a more direct



view of the endosteal surface of the pedicle drill tract with use of a 30-degree scope; however, this was not possible in our study because a 30-degree 1.9-mm needle arthroscope is not commercially available and is a limitation of our study. We suspect that the use of a 30-degree needle arthroscope would be particularly useful for drill tracts with very subtle or equivocal medial breaches by allowing a more direct view of the endosteal surface.

In our study, surgeons performing endoscopic grading of pedicle drill tracts were blinded to the specific number of breaches to reduce bias because of attempting to account for a known number of breaches. Furthermore, surgeons did not create initial pilot holes because of tactile feedback during drilling, the trajectory of drilling, or the location of the pilot hole potentially highlighting the number and/or location of breaches prior to intraosseous endoscopy. In addition to this, surgeons stood behind a nontransparent screen to minimize bias related to pilot hole location and drilling trajectory. While this meant that surgeons had to rely completely on videoendoscopic images to determine the grade of each drill tract, in clinical practice, surgeons would be expected to take into consideration all of these factors in combination with videoendoscopic images to make the most informed decision regarding the safety of a drill tract. In one study,<sup>14</sup> investigators passed a ball-tipped probe alongside the endoscope; however, this was not possible in our study due to the lack of sufficient space within the drill tract with the scope in place. It is possible that an improved rate of sensitivity would have been observed in our study had it been possible to pass a ball-tipped probe alongside the scope and probe the walls of the tracts. While investigators in 2 previously published studies<sup>14,16</sup> created drill tracts using a free-hand technique, we chose to create drill tracts with the use of 3DPGs in an effort to produce both partial and full breaches. A small discrepancy between the planned and observed number of specific breaches was identified in our study and, on the basis of the very high degree of accuracy associated with 3DPGs, was probably related to the lack of experience of the resident in training with use of such guides and is a limitation of our study.<sup>2-6</sup> It is possible that the use of press-fit 3DPGs or those held in place with Kirschner wires or even the use of antiskid drill bits could have reduced this discrepancy and is also a limitation of our study.

The overall number of breaches in our study was kept low, at just over 20%, to make them more difficult to find. However, because of this, the final number of specific grades of medial and lateral breaches was also quite low. Our principal aim was to assess the accuracy of intraosseous endoscopy to detect breached versus nonbreached drill tracts. An estimation of accuracy does not require a hypothesis test, and therefore the sample size chosen in our study was based on what has been used in previous publications.<sup>14-16</sup> Ninety-five percent confidence intervals, which are directly linked to sample size, have also been provided around our estimation of accuracy so

that the possible range of values the true accuracy may have can be identified.

The order in which surgeons first graded each tract after drilling was alternated to reduce bias on the time recorded to assign a modified Zdichavsky grade. This was because mild blood and bone debris were typically observed immediately after drilling and very briefly delayed visualization of drill tracts until passage of the scope and saline irrigation. Further, passage of the scope on the second occasion was potentially easier. Investigators in a previous study<sup>14</sup> reported similar findings, with hemorrhage within the pedicles clearing as soon as the endoscope was seated within the pedicle and irrigation commenced. The median time taken to assign a grade was significantly greater for surgeon 1 (approx 2.5 minutes) compared with surgeon 2 (1.5 minutes). In 2 previous studies,<sup>14,16</sup> the average time taken to fully visualize the interior of pedicle drill tracts was within 2 minutes. The cause of the difference between surgeons in our study is suspected to be related to the fact that surgeon 1 was the primary investigator and tended to obtain still images of pertinent findings during the endoscopy. It should also be noted that the time taken to assign a grade would have been dependent on how easy it was to pass the arthroscope and how quickly the tract could be clearly visualized; however, because the same person passed the arthroscope in every case and the order in which surgeons first graded each tract was alternated, the risk of bias should have been minimized.

Our second hypothesis was that endoscopic inspection of pedicle drill tracts would be associated with a high rate of reliability for the detection of nonbreached (grade 1 modified Zdichavsky) tracts and those with medial or lateral violations. This was based on the findings of 2 previous studies,<sup>14,16</sup> 1 involving an adult pig<sup>14</sup> and another that included 3 adult sheep,<sup>16</sup> in which investigators successfully identified all perforations, even as small as 2 mm in diameter. In our study, intraosseous endoscopy of pedicle drill tracts was associated with a very high specificity (ability to correctly identify nonbreached drill tracts), meaning that there was a very low rate of false positives. All 5 false positives, which involved 4 specific drill tracts, were assigned as grade 3 breaches. This most likely occurred because surgeons were not aware of the trajectory of any drill tracts and because of the difficulty in distinguishing a short grade 1 tract from a similarly short grade 3 breach. In the case of a grade 3b breach, which passes entirely through the transverse process, the drill tract will be lined with cancellous bone similar to a grade 1 tract, but it will appear inappropriately short. Interestingly, all 5 false positives were located in the thoracic spine (Table 1). In clinical cases, the length of the pilot hole would be measured with a depth gauge and compared with the planned CT measurements; however, this was not possible in our study because of our methodology. Radcliff and et al<sup>14</sup> described the visualization of paraspinous muscle fibers on endoscopic inspection of lateral pedicle wall breaches. Such muscle fibers

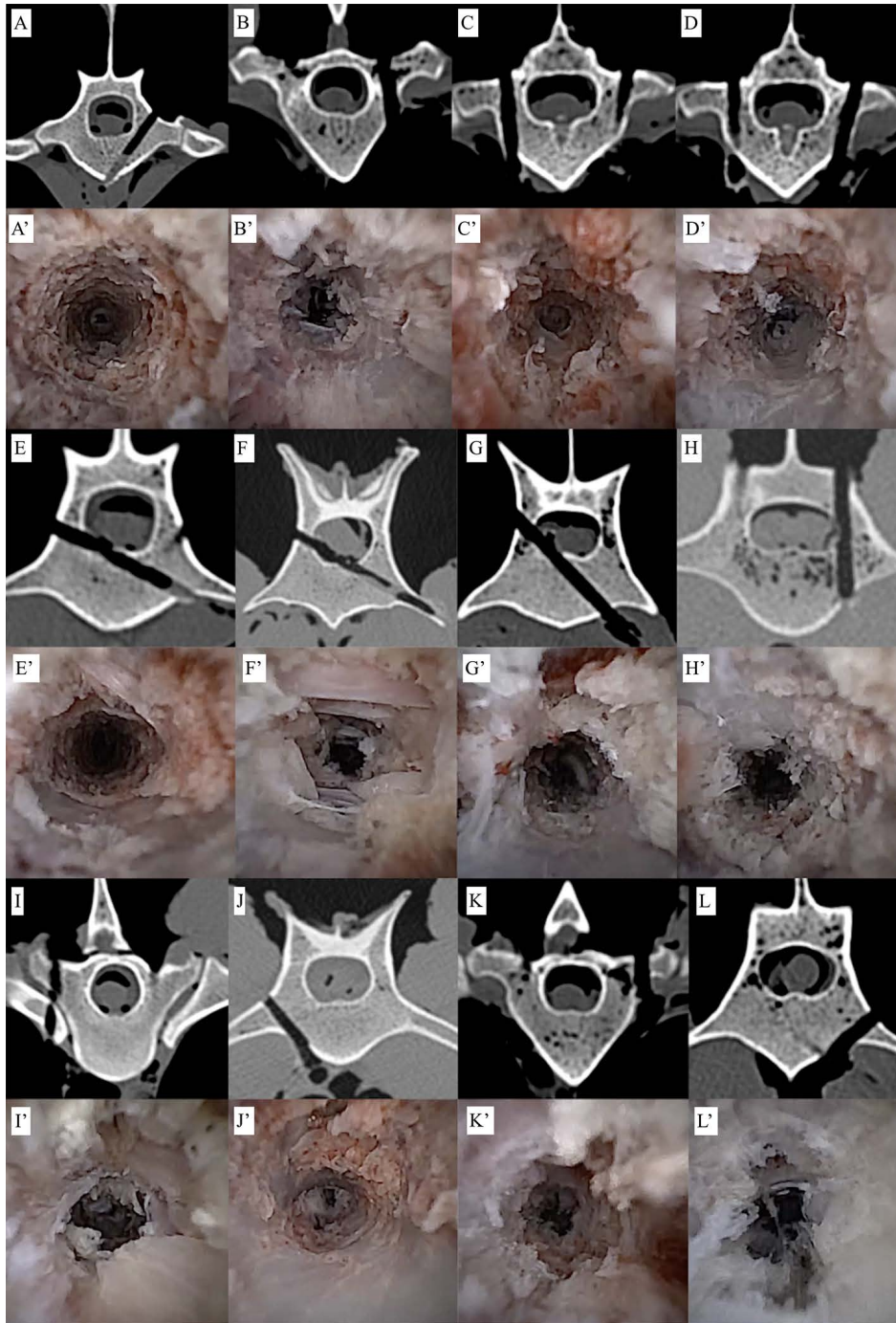
could not be clearly visualized with grade 3 breaches in our study, possibly because of its cadaveric nature in comparison to the study by Radcliff et al<sup>14</sup> that included a live pig. Visualization of the ventral longitudinal ligament was found to be useful in our study to confirm drill tract exit on the ventral aspect of the vertebra and would not be expected with a very lateral grade 3 breach.<sup>14,16</sup> In human spine surgery, penetration through the anterior cortex of the vertebra and therefore visualization of the anterior longitudinal ligament is avoided and considered a breach because of the risk of injury to vital structures.<sup>16,18</sup> Conversely, engagement of the ventral cortex is considered important in dogs for pull-out strength, and therefore our intent was to penetrate the ventral cortex in all drill tracts.<sup>1</sup> The sensitivity of intraosseous endoscopy to detect a medial breach (any grade 2 modified Zdichavsky) was only fair (71.4%) in our study. This occurred because of incorrect classification of 3 grade 2a breaches as grade 1 and classification of 1 grade 2b breach as grade 1. These grade 2a breaches were often quite subtle (**Figure 4**), and it is likely that placement of an implant would not be associated with deleterious consequences, but this is purely speculative. It is possible that grade 2a breaches would have been more easily identified using a 30-degree scope and is a potential limitation of our study. The PPV for detection of a medial breach in our study was 83.3% and occurred because 2 grade 3 breaches were assigned grade 2a by surgeon 1 (Table 1). In one of these cases, a grade 3b drill tract traveled through the thoracic transverse process and continued through the underlying rib in the same trajectory, giving the impression of a breach in between the 2 structures (Figure 4). In the other case, a grade 3a breach was classified as a grade 2a because the contralateral drill tract entered the medial aspect of the tract being evaluated, giving the impression of a breach (Figure 4). The sensitivity of intraosseous endoscopy to detect a lateral breach in our study was poor (60%). This occurred because of incorrect classification of 2 grade 3a breaches as grade 1 and another as grade 2a and classification of 1 grade 3b as a grade 2a (Figure 4). This is in part related to the difficulty in distinguishing a short grade 1 tract from a similarly short grade 3 breach. With greater experience with intraosseous inspection of pedicle drill tracts, grade 3a breaches may be differentiated from grade 1 by the combination of a relatively short drill tract combined with a somewhat sloped or oblique ventral ring of cortical bone, which occurs as a result of the drill bit exiting in a more dorsal location laterally compared with medially. A grade 3b breach may be identified by the presence of a short drill tract, with a ring of ventral cortical bone oriented approximately perpendicular to the drill tract, and the possible absence of a ventral longitudinal ligament depending on how lateral the tract is.

We recognize several important limitations in this study. This was a cadaveric study, and therefore endoscopic visualization of drill tracts would not have been impacted by active bleeding from the

bone, and how this would have affected our results is unknown. In 2 previous studies,<sup>14,16</sup> bleeding was not found to be a problem and quickly subsided with placement of the scope and the initiation of saline irrigation. A single large breed was included in this study, and the ability to perform this technique is limited by the size of the patient and associated drill tracts because the scope and associated cannula must be able to fit within such drill tracts. Further studies are required to determine the feasibility of this technique in smaller breeds, but we believe that the technique will be limited by the size of the pedicle drill tracts. The number of breaches in our study was also quite low. The surgical approach in this study was larger than would be required in a clinical case, which may have positively impacted our ability to perform endoscopic inspection of drill tracts. Although no specialized pumps or pressure bags were used in this study, with saline allowed to flow by gravity only, in clinical cases, the consequences of saline irrigation into the retroperitoneal or retropleural space or vertebral canal in cases with grade 2 breach are unknown. Further, in cases with possible dural laceration related to a medial breach, the use of a pressure pump could lead to flow of irrigation fluid into the subarachnoid space and raised intracranial pressure. Radcliff et al<sup>14</sup> found no evidence of significant spinal cord or nerve root compression, fluid extravasation into the vertebral canal, or retrograde flow of irrigation fluid into the pedicle tracts; however, cannulation of only 8 tracts was performed in that study, and only 2 of 6 iatrogenic breaches were medial. Furthermore, great care should be taken when passing the scope to prevent inadvertent uncontrolled passage of the scope beyond the ventral cortex and injury to intrathoracic or retroperitoneal structures. Previous studies have described the use of a 30-degree needle arthroscope; however, such a 1.9-mm scope is not commercially available to our knowledge.<sup>14,16</sup> Further studies comparing the accuracy of 0-degree and 30-degree needle arthroscopes for the inspection of canine pedicle drill tracts should be considered. Finally, passage of the needle arthroscope was performed by a first-year resident in training, and it is possible that this influenced the visualization and evaluation of pedicle drill tracts in our study.

Endoscopy of pedicle drill tracts is technically feasible in the canine thoracolumbar and lumbar spine and was associated with excellent specificity, fair sensitivity for detection of medial breaches, and poor sensitivity for detection of lateral breaches among surgeons with no training or previous experience with intraosseous endoscopy. It is likely that with further experience and training with this technique that improved reliability for the detection of breaches would be observed. This technique has substantial scope in clinical practice regardless of whether 3DPGs are available, allowing surgeons to confirm the integrity of a drill tract before implant placement. Further studies are required to investigate the safety and accuracy of this technique in clinical cases.





**Figure 4**—Transverse plane MPR computed tomographic (bone window; window width and length in the region of 2,500 and 500, respectively; 0.75-mm slice thickness) and corresponding intraosseous endoscopic images of grade 1 (A–D), grade 2 (E–H), and grade 3 (I–L) modified Zdrichavsky drill tracts assigned the incorrect grade by 1 or both surgeons. Images A, E, F, I, and J are from cadaver 1. Images B, C, D, G, H, K, and L are from cadaver 2. Extending from left to right across A–D is T13L (A and A’), incorrectly assigned grade 3a by surgeon 2; T7L (B and B’), incorrectly assigned grade 3b by both surgeons; and T11R (C and C’), and T11L (D and D’), both incorrectly assigned grade 3a by surgeon 2. Extending from left to right across E–H is L1R (E and E’), a grade 2a, incorrectly assigned grade 1 by surgeon 1; L4R (F and F’), a grade 2b, incorrectly assigned grade 2a by surgeon 1; L2R (G and G’), a grade 2b, incorrectly assigned grade 2a by surgeon 1 and grade 1 by surgeon 2; and L7L (H and H’), a grade 2a, incorrectly assigned grade 1 by both surgeons. Extending from left to right across I–L is T9R (I and I’), a grade 3b, incorrectly assigned grade 2a by surgeon 1; L6R (J and J’), a grade 3a, incorrectly assigned grade 1 by both surgeons; T8L (K and K’), a grade 3b, incorrectly assigned grade 3a by surgeon 2; and L4L (L and L’), a grade 3a, incorrectly assigned grade 2a by surgeon 1. The left side of all CT images is the right side of the dog. The upper half of endoscopic images represents the medial wall of the pedicle drill tract, and the lower half represents the lateral wall.

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