Original Research

Feasibility and Accuracy of Pedicle Screws in the Feline Thoracolumbar Spine

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Vet Comp Orthop Traumatol

Abstract

Objective To evaluate the feasibility and accuracy of vertebral pedicle screws in cats using a custom 3D-printed drill guide and 3D-printed vertebral columns.

Methods To simulate the surgical procedure, six vertebral columns from adult cats were 3D-printed. The columns were printed with a radiolucent material (PLA enriched with calcium carbonate—PLA+). One 3D-printed guide was created for each vertebra (from T10 to L7). Each preplanned hole was drilled and filled with a graphite cylinder for better visualization of the tunnel. All the phantoms were CT-scanned after the drilling operation. Each hole was graded using a modified classification scheme (grades 0 to 3) and compared to the planned tunnel angle. We enrolled one 5-year-old female patient with spinal trauma requiring vertebral stabilization presented at our hospital.

Results A total of 126 holes were drilled. The overall mean screw deviation angle was 0.61 degrees (SD = 0.72). In safety evaluation, 117 (93%) screws were contained in the pedicle (grade 0), 7 screws (5.5%) were outside the pedicle by less than 0.5 mm (grade 1), and 2 (1.5%) screws were between 0.5 and 1 mm outside the pedicle. In the thoracic segment, all the holes (48/48) were classified as a grade 0, while in the lumbar segment, with a total of 78 holes drilled, there were 69 holes classified as grade 0 (88%), 7 holes classified as grade 1 (8.9%), and 2 holes classified as grade 2 (2.5%). The feline patient had suffered a T12 complete oblique vertebral body fracture. A total of six 1.7 mm screws, 20 mm long, (Fix-In, INTRAUMA) were placed: three in T12 and three in T13.

Clinical Significance Overall, there was a mean deviation of the hole angle from the planned angle of 0.61 degrees. The overall safety was 91.2% (screws graded as 0). A statistically significant association between screw grades and vertebral segment was found (*p*-value 0.02) as all the thoracic vertebrae are grade 0, while grade 1 and grade 2 were found only in the lumbar segment. Using pedicle screws in cats' vertebrae may reduce surgical trauma, as it requires exposure of only the most dorsal portion of the vertebral lamina, avoiding the need to expose the costal attachments. Also, placing cement dorsally is easier and can incorporate screw heads bilaterally. We effectively and safely performed the surgical procedure in one clinical case. Based on our results, the use of pedicle screws, previously applied in canine patients, could also be extended to feline patients, provided that 3D-printed guides are used to ensure accurate placement.

Keywords
- bioengineering
- fracture repair
- orthopaedic devices
- spine surgery

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Introduction

Vertebral fractures and instability are among the most common traumatic causes of spinal cord injury in cats.[1] The patient's neurological status at presentation is one of the key factors for deciding whether to operate or not.[2] Treatment usually involves realignment and stabilization of the spinal segment involved. Vertebral stabilization is achieved with implants, such as pins or screws, placed within the pedicles or vertebral bodies and polymethylmethacrylate, stainless,[3] or titanium plates.[4,5] Most techniques require precise insertion of bicortical implants into the vertebral bodies to achieve maximal bone purchase and care must be taken to avoid penetration of the spinal canal.[6,7] In cats, although different methods could be used, screw stabilization remains one of the most popular. The only optimal safe implantation corridors reported in cats involve holes drilled in the vertebral body perpendicular to the midsagittal plane (90 degrees) or with a small angle (≤10 degrees) of deviation from the optimal angle.[8] In cats, potential corridors involving the vertebral pedicles were ruled out because of their small size.[4]

Pedicle screws are one of the preferred methods for stabilizing the vertebral column in human medicine due to their superior biomechanical properties, ensuring stability and effective correction of spinal deformities. Several techniques for pedicle screw placement have been described in human neurosurgery, each with varying outcomes in terms of accuracy. The freehand technique has reported success rates for screws fully embedded within the pedicle ranging from 68.7 to 93%.[9–12] Imaging-assisted methods improve accuracy, with C-arm fluoroscopy achieving a 92.78% success rate and O-arm with computer navigation yielding 95.4 to 98.13%.[10]

3D-printed custom guides also enhance safety and precision. Studies comparing 3D-printed guides to the freehand technique found that 96.1% of screws placed with 3D-printed guides were within the "safe zone," compared to 82.9% with the freehand method. These guides have demonstrated accuracy and efficiency comparable to O-arm systems but without the high costs and increased radiation exposure associated with advanced imaging systems.[13] In veterinary medicine, the use of pedicle screws is well-documented in canine species. However, to date, there are no published reports on pedicle screw use for vertebral stabilization in cats.[14–17] Based on the high accuracy of pedicle screws in the thoracolumbar spine in the dog,[17] and the high accuracy of 3D-printed guides both in human and veterinary medicine, we evaluated the feasibility and accuracy of vertebral pedicle screws in cats using a custom 3D-printed drill guide and 3D-printed vertebral columns. Each tunnel position was measured and classified, using a classification scheme from the human literature.[18] Furthermore, we compared the presurgical planning measurements with the CT scan images obtained after drilling to evaluate the precision and accuracy of the 3D-printed guides.

Materials and Methods

Case Enrollment

Computed tomography (CT) scans of the thoracolumbar spine of six cats including at least from the 6th lumbar vertebra (L6) to the 12th thoracic vertebra (T12) were included. Informed consent was obtained from the owners of all cats whose CT scans were used in this research.

3D Phantoms and Guides Design

CT datasets were extracted and exported into a free-source software (Slicer 3D) for segmentation using a threshold of 300 Hounsfield units (HU) and manually eliminating redundant or aberrant voxels. The STL file created was then exported into a free-source software (Blender 3.6) for planning and creation of patient-specific vertebral guides.

To simulate the surgical procedure, vertebral columns of adult cats were printed. Cat breed and weight were recorded. The columns were printed with a radiopaque material (PLA enriched with calcium carbonate—PLA+, SunLu) that resembles bone material when exposed to X-ray.[19] For each column, vertebrae from T10 to L7 were selected, and guides with two drill sleeves (one for each side) were created. Vertebrae with pathological changes were excluded from the study. Additionally, the most cranial and caudal vertebrae were excluded if they were not fully visible in the CT scan.

Drill guides were designed in Blender 3.6, starting by placing a 1.3-mm cylinder in the ideal hole trajectory. All drill sleeves account for a 1.3-mm drill bit that would suit the placement of a 1.7-mm screw. Drill guides had a 1.3-mm internal diameter and 20-mm long cylindrical sleeves. A specific footprint at the interface between the guide and the vertebral lamina was created for each guide via a Boolean operation. Guides were printed from white resin using a STL printer (Form2, Formlab) with a 50-micron layer height (►**Fig. 1**).

Graphite cylinders of 1.3 mm in diameter (Staedtler®, Nuremberg, Germany) were used to simulate implants in their position in order to avoid the typical hyperattenuation caused by metallic K-wires.

Screw Trajectory

The 1.3-mm cylinder used to simulate the drill bit was rotated and translated in all directions to obtain parallelism to the spinal process in the mediolateral view, and to the pedicle cortex in the caudocranial view. The trajectory direction relative to the midsagittal plane varies depending on the vertebral segment (►**Fig. 2**). The ideal entry point was identified as equidistant from the two intervertebral disks from the craniocaudal perspective and as perpendicular as possible to the pedicle's most proximal surface, to avoid slipping of the drill bit during the initial drilling operation.

Surgery Simulation

Each guide was assigned to its vertebra. During the surgical simulation, the assistant firmly held the guide in its unique position, while the primary surgeon performed the drilling operation. All the holes were then filled with 1.3-mm graphite cylinders to show the hole trajectory. To account for the 1.7-mm screw planned to be used in real cases, the evaluation for "safe screw placement" was done by accounting for the 0.2-mm extra thickness on both sides of the 1.3-mm graphite cylinder during the postoperative CT evaluation.

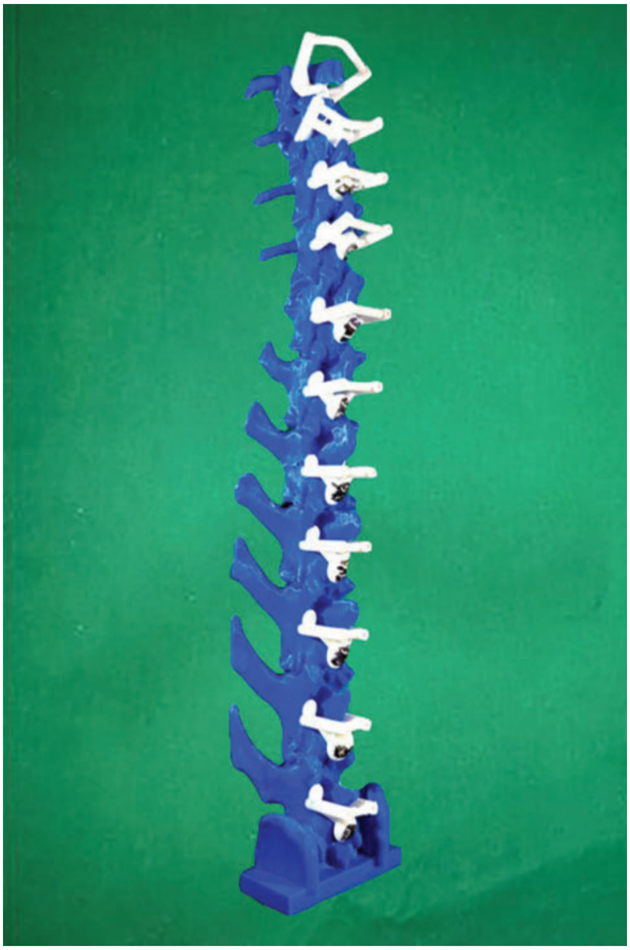

Fig. 1 3D-printed phantom (case 4), with each drill guide positioned in its unique location.

Evaluation of the Accuracy and Safety of Drill Guide Templates

A comparison between planned screw trajectory angles and post-surgery hole angles was performed by superimposing the pre- and post-drilling vertebral columns using an add-on called "Iterative Closest Point (ICP)." It is an algorithm employed to minimize the difference between two clouds of points or meshes. It does ensure the less possible deviation in terms of relative position and orientation between the two selected objects.

The degree of angle differences in the mediolateral direction was measured between the planned trajectory and the actual hole trajectory. Although only the mediolateral deviation was used for the calculation of the deviation angle, this was based on the rationale that errors in this direction are the most likely to result in medial or lateral pedicle penetration. However, bone tunnels were carefully evaluated in all directions, including craniocaudal, to assess cortical penetration (►**Fig. 3**). Furthermore, each single screw trajectory was classified based on a modified classification scheme from the human literature. Human classification systems commonly use 2-mm increments. Considering that the average diameter of a pedicle screw in humans ranges from 5 to 7 mm, with the classification increment being about one-third of the screw diameter, we applied the same reasoning by using a 0.5-mm increment since we plan to use 1.7-mm screws[18,20]:

- Grade 0: no pedicle penetration
- Grade 1: 0.5-mm internal or external perforation of the pedicle
- Grade 2: between 0.5 and 1 mm of perforation of the pedicle or 50% of the screw trajectory outside of the pedicle

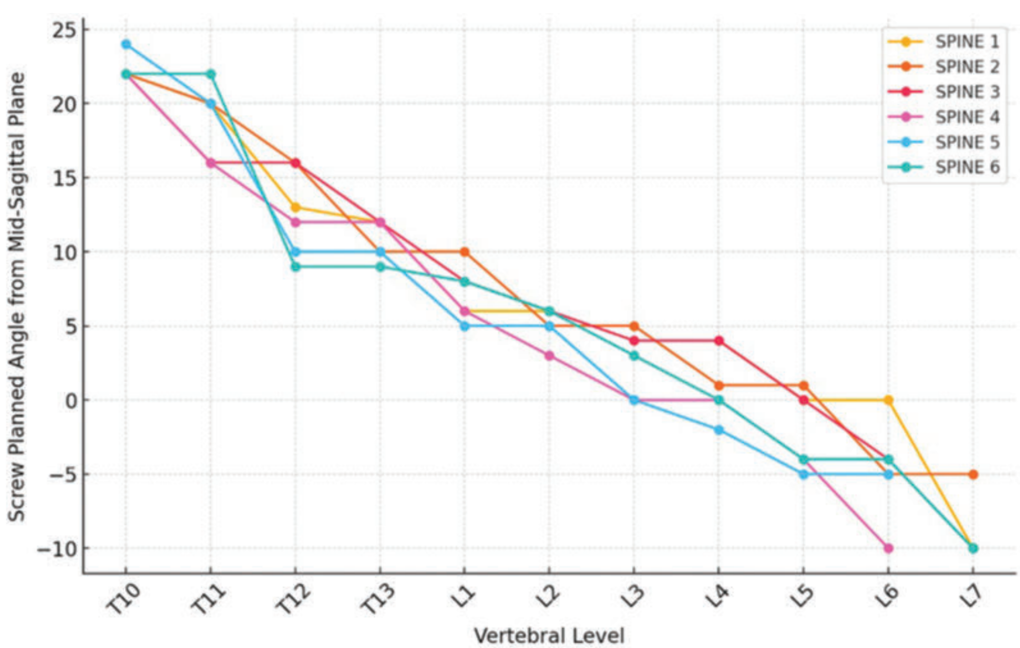

Fig. 2 The screw planned angle from the midsagittal plane for each vertebra and each spine.

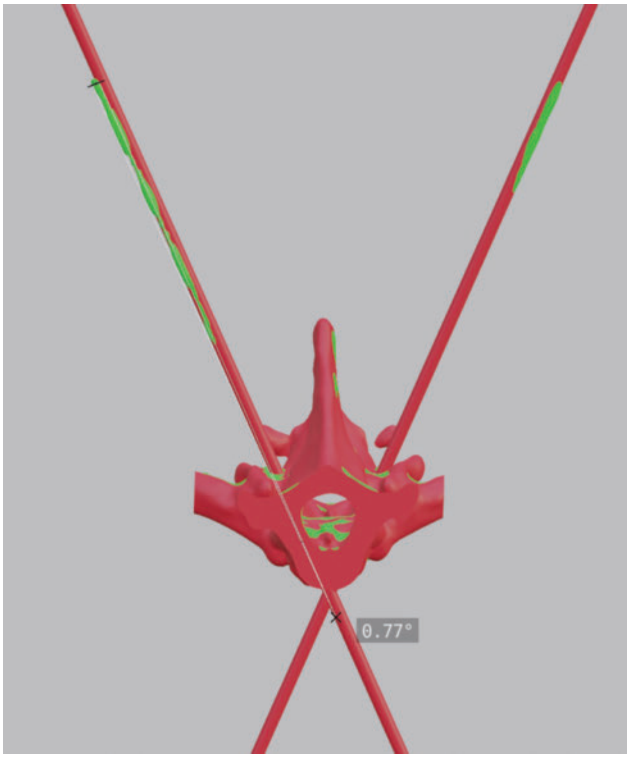

Fig. 3 After careful superimposition of the pre- and post-drilling vertebral bodies, the variation between the preplanned and the actual tunnel angle is measured.

- Grade 3: 1 mm or complete perforation of the pedicle, with 100% of the screw trajectory outside the pedicle

For each trajectory with a grade bigger than 0 we reported whether the pedicle breach was lateral or medial.

Statistical Analysis

Vertebrae were grouped into three groups: thoracic vertebrae, lumbar vertebrae from L1 to L3, and lumbar vertebrae from L4 to L7. Moreover, two groups were created, one with the two Maine Coon cats and a second with the other four mixed-breed cats.

The quantitative variable was reported as mean and standard deviation (SD), while categorical variables were expressed as counts and percentages in each category. Statistical differences in the screw angulation error were analyzed by the Mann-Whitney test or by the Kruskal-Wallis test, according to the number of groups. Pearson's chi-squared test was used to evaluate associations in qualitative variables. The significance level was set at $p < 0.05$. Data were analyzed using the statistical software R.

Clinical Cases—Surgery

A cat presenting for a vertebral fracture after a road traffic accident. The patient underwent a CT scan of the vertebral column using a slice thickness of 0.6 mm. Surgery was performed by a board-certified surgeon (F.C.) the day after the admission of the patient, to allow the design and 3D printing of the guides during the night. The guides were designed in a way to account for two pedicle screws in T12 and two pedicle screws in T13 vertebra. Any more screws that the surgeon would like to insert needed to be inserted freehand using the technique described by Vallefuoco.[4,8]

Results

3D Phantoms

Six columns from adult cats were 3D-printed. Two of the cats (spines two and six) were Maine Coon. A total of 126 holes were drilled. The overall mean screw deviation angle was 0.61 degrees (SD = 0.72). In safety evaluation, 117 (93%) screws were contained in the pedicle (grade 0), 7 screws (5.5%) were outside the pedicle by less than 0.5 mm (grade 1), and 2 (1.5%) screws were between 0.5 and 1 mm outside the pedicle (grade 2). All the holes classified as grades 1 or 2 were contained by more than half their thickness by the pedicle and exited the pedicle laterally. All the holes breached the pedicle laterally. There was no hole classified as grade 3 and there were no grade 1 or 2 screws in the thoracic vertebrae (►**Fig. 4**).

In the lumbar segment, with a total of 78 holes drilled, there were 69 holes classified as grade 0 (88%), 7 holes classified as grade 1 (8.9%), and 2 holes classified as grade 2 (2.5%) (►**Fig. 5**). The mean screw deviation angle in the lumbar segment was 0.77 degrees (SD = 0.82). In the thoracic segment all the holes (48/48) were classified as a grade 0, and the mean screw deviation angle was 0.43 degrees (SD = 0.43) (►**Fig. 6**).

The comparison between Maine Coon cats and mixed-breed cats showed no significant difference in screw angle error or screw grades ($p = 0.73$). Similarly, no significant difference in accuracy was observed between right and left side screws ($p = 0.64$).

Clinical Case

One female cat, 5 years old, with a T12 complete oblique vertebral body fracture, that presented with bilateral plegia and deep pain response was enrolled. It underwent spinal stabilization in the T12–T13 segment. One guide for T12 and one for T13 were built. Both had two drill sleeves each, one on the right side and one on the left side. A total of three 1.7-mm screws (Fix-In, INTRAUMA) in each vertebral body were placed. Just two of the three screws were pedicle ones while the third one was inserted almost perpendicular to the vertebral body.[8] After insertion of the vertebral screws, antibiotic-impregnated polymethacrylate cement (De Puy Synthes™) was poured dorsally. Routine closure of the skin was performed. We checked with a postoperative CT scan the positioning of the implants. Both the pedicle screws and screws perpendicular to the spinous process were fully contained within the pedicle or the vertebral body, accounting for a total of six "grade 0" vertebral screws. The cat did not develop any perioperative complications from the surgery. We could not obtain further postoperative follow-up after discharge (►**Fig. 7**).

Discussion

In this study, we evaluated the accuracy and safety of pedicle screws in the thoracolumbar spine of cats. Overall, there was

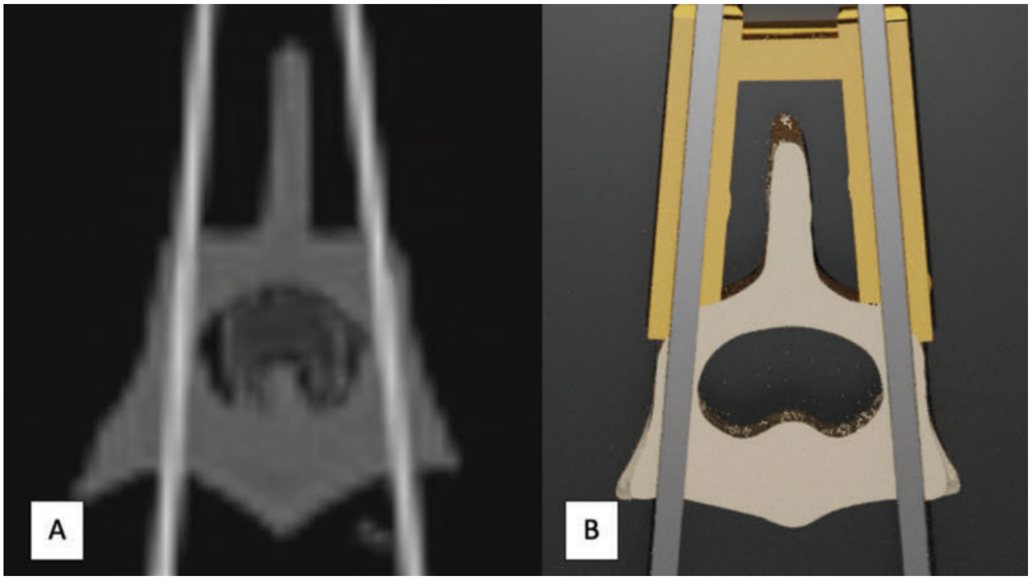

Fig. 4 (**A**) On the left, the post-drilling CT, representing two tunnels with no lateral or medial penetration of the pedicle, bilaterally graded as 0. (**B**) On the right is the planning of the ideal trajectory to obtain a grade 0 tunnel.

a deviation of 0.61 degrees between the planned angle and the actual executed tunnel. Penetration of the spinal canal medially was not observed in any of the cases, while in nine cases the tunnel was piercing partially through the vertebral pedicle laterally, classified in seven cases as grade 1 and in two cases as grade 2. The overall safety (tunnel graded as 0) was 91.2%. A statistically significant association between screw grades and vertebral segments was found (*p*-value 0.02). All the thoracic vertebrae were graded 0, while grades 1 and 2 were found only in the lumbar segments. There was no statistically significant correlation between screw grade and screw angle error (*p*-value 0.15). Studies evaluating the use of pedicle screws using 3D-printed guides in dogs and humans have reported similar safety rates to our study. In dogs, success rates varied across studies, ranging from 79.3 to 96.7%. Recently, Violini et al reported an optimal screw placement rate of 84% in the thoracolumbar column in brachycephalic breeds.[15–17,21,22]

Similarly in humans, studies evaluating pedicle screw insertion with 3D-printed guides in the thoracolumbar spine found safe placement rate of between 91.5 and 96.1%.[13,23,24]

To the best of our knowledge, no previous studies found a significant difference in screw placement safety between the lumbar and thoracic spine. We assume this finding in our

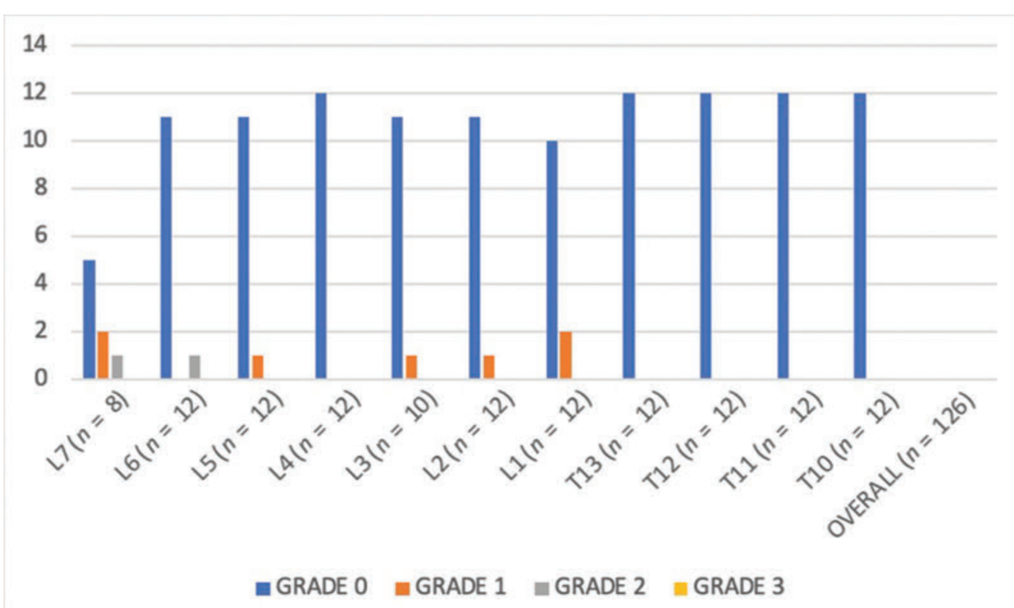

Fig. 5 Classification of 126 screw holes drilled in feline models of the thoracic and lumbar spine. Grade 0: no pedicle penetration; grade 1: 0.5-mm internal or external perforation; grade 2: between 0.5 and 1 mm of perforation of the pedicle or 50% of the screw trajectory outside of the pedicle; grade 3: 1 mm or complete perforation of the pedicle, with 100% of the screw trajectory outside the pedicle.

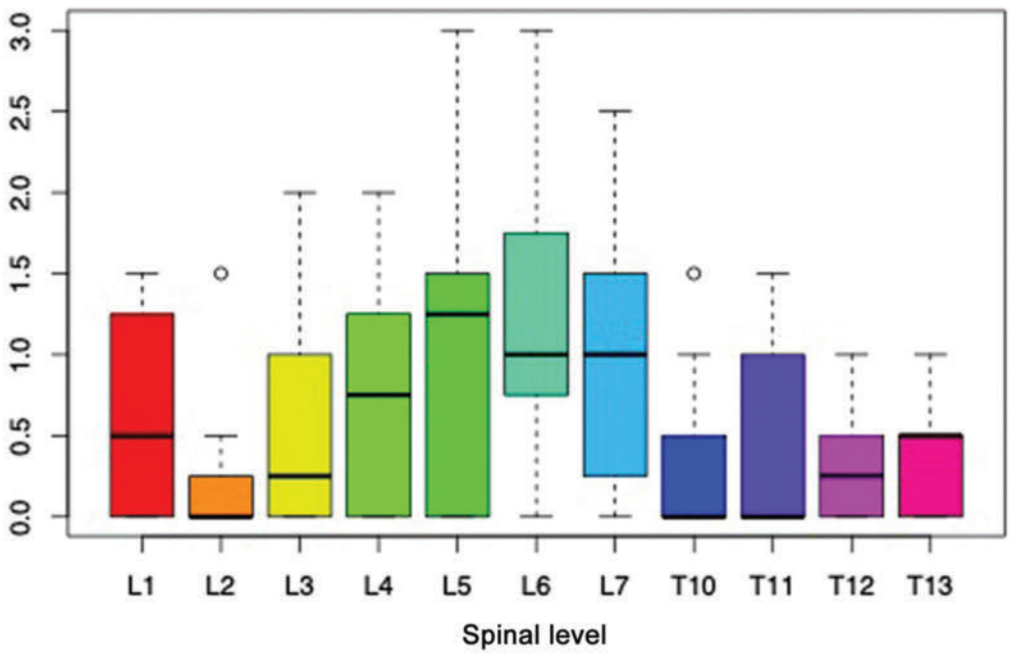

Fig. 6 For each spinal level, the box plot illustrates the distribution of tunnel angle errors, defined as the absolute difference between the planned and achieved screw insertion angles. The interquartile range (IQR) is represented by the height of each box, and the horizontal line within the box indicates the median value.

study is related to the thicker pedicles of the thoracic vertebrae compared to the lumbar vertebrae, a factor further accentuated by the already small size of feline vertebrae.

Despite the higher probability of pedicle invasion in the lumbar segment, safety (91.2%) was comparable with those of pedicle screw stabilization in dogs, with reported percentages in the literature ranging from 89.6[16] to 96.7%.[13]

The comparison between Maine Coon cats and mixed-breed cats showed no significant difference in screw angle error or screw grades ($p = 0.73$). Similarly, no significant difference in accuracy was observed between right and left side screws ($p = 0.64$). However, these findings should be interpreted with caution, as the limited sample size may have resulted in insufficient statistical power, increasing the risk of a type II error.

Currently, the only described method for freehand placement of screws in the feline thoracolumbar spine comes from a study by Vallefuoco et al.[8] In that study, to ensure a safe corridor, the median trajectory angle in respect to the optimal angle calculated from the midsagittal plane was found to be 90.2 degrees in the thoracic segment and 90.5 degrees in lumbar vertebral segments. The use of pedicle corridors was ruled out, as the pedicle was considered too thin to allow for safe freehand placement. Screws applied freehand with the technique published by Vallefuoco proved to be safe and allowed for good accuracy and safety.[4,8]

However, the use of pedicle screws in some select cases could be beneficial for the following reasons: (1) the need to expose the lateral aspect of the vertebral body increases the surgical injury, can be time consuming, and often the visualization of the optimal starting drilling point can be difficult to achieve. This is especially true in overweight patients and in thoracic vertebrae due to the costal attachment. (2) Placing the sterile polymethacrylate bone cement dorsally instead of laterally is technically easier and could be beneficial in terms of strength: one single cement pour can incorporate the screw heads bilaterally.

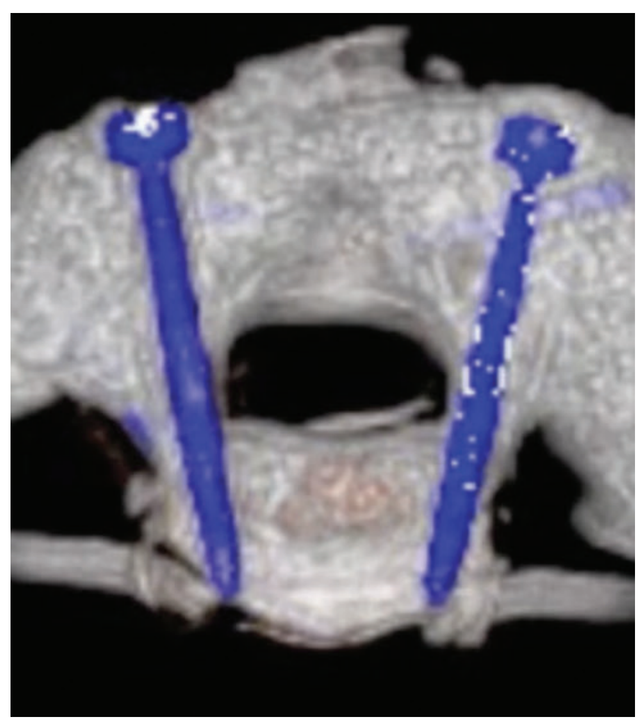

Fig. 7 Postoperative sagittal CT scan of T12, optimized to detect metallic objects and show them as blue.

Pouring cement dorsally allows for a thicker pour and acts along the main axis of flexion and extension movement of the column. However, this latter is just a speculative assertion and would need further study to be confirmed.

It is also important to consider that some surgeons prefer to use 3D-printed guides for most spinal stabilization procedures whenever feasible. Given this preference, designing guides to assist with the placement of vertebral screws as described by Vallefuoco et al[4,8] introduces several challenges. First, such guides would need to be wider and bulkier compared to those designed for pedicle screw insertion. Second, securing a stable press-fit on the lateral aspect of the vertebra is typically more time-consuming and difficult than achieving fixation on the dorsal surface. Third, the drill sleeves required for perpendicular screw trajectories are more likely to interfere with the surrounding epaxial musculature. For these reasons, if a surgeon is already planning to use 3D guides in a feline patient, it would likely be simpler and more efficient to design them specifically for pedicle screw placement.

When pedicle screws are used, the trajectory direction relative to the midsagittal plane varies depending on the vertebral segment and is generally much more parallel to the sagittal plane compared to the screws described by Vallefuoco, which, conversely, are inserted almost perpendicularly.[4,8]

It is the authors' opinion that the deviation between the preoperative planned trajectories and postoperative screw corridors simulated by the graphite cylinders in our in-vitro testing was small enough to justify the use of pedicle screw in a clinical case. Our clinical case using pedicle screws in a cat is encouraging, although a large population is needed to support this technique. We acknowledge that there is no follow-up and that this does not provide definitive scientific evidence, but we believe it may serve as a practical example of the potential application of this fixation method.

The use of pedicle screws in cats, assisted by 3D-printed guides, allows for adherence to the key criteria that should be considered when placing pedicle screws: (1) Bicortical implantation with maximum bone purchase; (2) threaded implants with the largest possible diameter; (3) implantation corridors with a wide margin of safety; (4) implant patterns that enable the placement of two or three implants per vertebra.

In this study, to utilize the smallest possible screw diameter without compromising strength, 1.7-mm locking screws (Fix-In INTRAUMA) were chosen instead of the commonly used 2.0-mm cortical screws, as described by Vallefuoco et al.[4,8] This difference is not significant in terms of strength, as the variation in core diameter is minimal.

The use of pedicle screws in cats without the aid of 3D-printed guides may lead to spinal canal invasion or suboptimal bone purchase due to the limited size of the pedicles' section. In the current study, as a proof of concept, only one screw per side per vertebra was used. It is our opinion that inserting up to two screws per side and applying some degree of inclination in the craniocaudal plane to avoid collision between the screws' tips of the left and right side is feasible.

In this in vitro study, the operator was able to visually evaluate the entire spine, which may also have contributed to the great accuracy of the drill guide template in the 3D-printed phantoms. As a subjective finding, the authors think that drilling PLA is more difficult than drilling bone because the drill bit tends to overheat the plastic which may melt instead of being cut if the drilling operation is not performed slowly. The ability to precisely evaluate the tunnel location, using graphite cylinders, has been useful to avoid the typical hyperattenuation caused by metallic K-wires.

The main limitation of the current in vitro study is the use of 3D-printed plastic models instead of feline cadavers. The absence of soft tissues and the inability to replicate the mechanical properties of bone, such as hardness and density, may have led to an overestimation of the accuracy of pedicle screw placement. Additionally, bone quality, which plays a critical role in clinical outcomes, was not accounted for in this model. Furthermore, the study lacks a sufficient number of clinical cases and long-term outcome data to fully evaluate the safety and applicability of this technique in a real clinical setting. Future studies involving feline cadavers and larger cohorts of clinical patients are essential to validate the findings and establish the real clinical reliability of this method.

A limitation when using this technique in a real clinical setting is the need to have both a team and equipment immediately available that can design and 3D print guides quickly, within just a few hours.

In conclusion, we are the first to report the use of pedicle screws, widely described in canine literature, in the feline spine. The drill guide system to drill holes for pedicle screw placement in a 3D phantom of adult cat thoracolumbar columns was useful and accurate. The safety was greater in the thoracic segments compared to the lumbar segments. We effectively and safely performed the surgical procedure in one clinical case.

Authors' Contribution

M.R., F.C. and A.P. contributed to the conception, study design, acquisition of data, data analysis and interpretation. M.M. contributed to the study design and data analysis and interpretation. L.V. contributed to acquisition of data, data analysis and interpretation. M.R. drafted, revised the submitted manuscript. F.C., M.M., L.V. and A.P. drafted, revised, and approved the submitted manuscript. All authors are publicly responsible for the relevant content.

Conflict of Interest

None declared.

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