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Use of a Smartphone Digital Goniometer Combined with the Freehand Pedicle-Probing Technique for Repair of a Comminuted L6 Fracture in a 4 kg Dog

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Abstract

A 10-month-old, 4 kg, Bichon Frise cross was referred for surgical stabilization of a highly comminuted L6 vertebral fracture after a road traffic accident. Nonambulatory paraparesis was present, with weak voluntary motor function in both pelvic limbs. Computed tomography (CT) of T6 to Cd1 identified a highly comminuted fracture of vertebral body and cranial endplate of L6 with severe narrowing of vertebral canal. A left-sided L6 pediculectomy was performed. The cauda equina was mildly bruised. Smaller bone fragments were removed, whereas larger bone fragments were depressed ventrally. Two 1.5-mm cortical screws were inserted into pedicles of L7 and a further two 2.0-mm screws into L5 vertebral body using the pedicle-probing technique. Following exposure of underlying cancellous bone, a smartphone digital goniometer, held by a nonsterile assistant, was used to guide advancement of a blunted Kirschner wire acting as a probe according to preoperative CT-determined safe angles. Postoperative CT identified excellent vertebral column alignment with improvement in spinal cord compression and optimal placement of implants at L5 and L7 (grade 1 modified Zdichavsky). Repeat CT at 3 months postoperatively identified well-seated implants. This report highlights that use of a smartphone goniometer may be a useful adjunct to the freehand pedicle-probing technique to guide correct trajectory of the probe and may also have application in other regions of the spine.

Keywords
- vertebral fracture
- pedicle-probing technique
- smartphone goniometer
- spinal
- dog

Introduction

The use of pedicle pins or screws in combination with polymethylmethacrylate (PMMA) or titanium rods offers a strong and versatile method of spinal stabilization in dogs.[1] Several techniques have been used to guide insertion of such pins or screws into the canine thoracolumbar spine including use of three-dimensional (3D)-printed patient-specific drill guides,[2–8] fluoroscopy,[9,10] a free-hand technique based on preoperatively calculated safe corridors,[11] and a modification of the free-hand technique known as the pedicle-probing technique.[12–15] While the use of 3D-printed patient-specific drill guides has become increasingly popular in veterinary spine surgery and is associated with a very high

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rate of accuracy,[2–8] the hardware and software required to produce these guides are not universally available and external sourcing of such guides can be associated with treatment delays.[16]

A pedicle-probing technique has been described for pedicle screw placement in people and in dogs.[12–15,17–21] It involves creation of a cortical defect (decortication) at the ideal pedicle screw/pin entry site, probing of cancellous bone of the pedicle to establish and confirm a safe trajectory, before drilling the pilot hole for the definitive screw/pin.[12] The pedicle-probing technique does not negate the need to preoperatively measure ideal pin insertion angles and to follow these angles intraoperatively.[12] Traditionally, the freehand technique has involved the use of intraoperative plastic or metal goniometers; however, these can be cumbersome and require careful positioning of both arms of the goniometer.[15] In the case described herein, we report the use of a smartphone digital goniometer, held by a nonsterile assistant, in combination with the freehand pedicle-probing technique for instrumentation of a highly comminuted L6 vertebral fracture in a 4 kg dog.

Case History

A 10-month-old, 4 kg, male Bichon Frise cross was referred for surgical stabilization of a highly comminuted sixth lumbar (L6) vertebral fracture after having been hit by a car the day before. On examination at the primary veterinary clinic, the dog was nonambulatory but demonstrated voluntary movement in both pelvic limbs. Radiographs of the lumbar spine were obtained and identified a comminuted fracture of L6 (►**Fig. 1**). The dog was treated with meloxicam. On the morning of referral, the dog was able to put weight on the right pelvic limb with support under the body.

On examination at our institution, the dog was bright, alert, and responsive. The dog was nonambulatory but demonstrated voluntary movement in both pelvic limbs, more on the right side. Cranial nerves and thoracic limbs were normal. There was delayed paw placement and hopping in the pelvic limbs, with normal withdrawal, patellar, and sciatic reflexes. Deep pain was present in the pelvic limbs. Tail movement and the perineal reflex were reduced. There was severe pain on palpation of the lumbar area. The

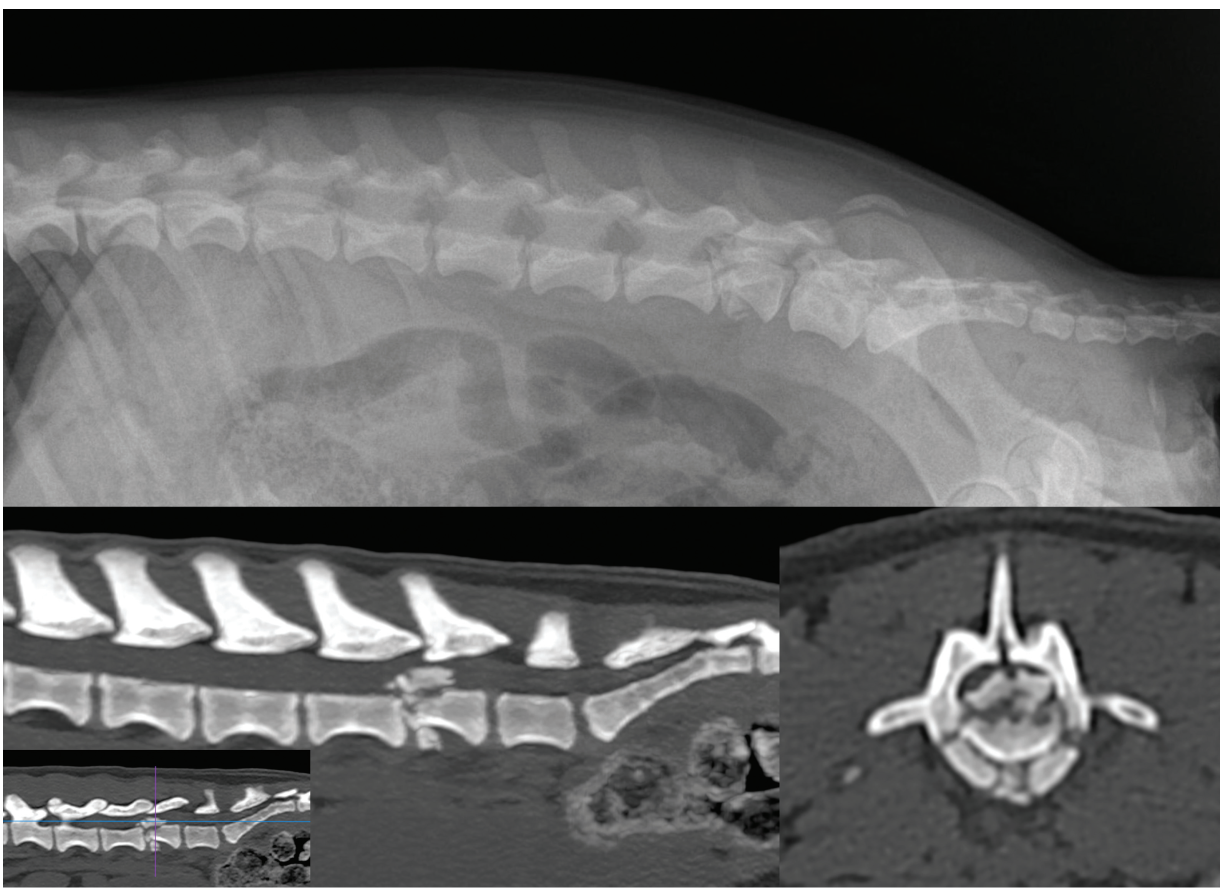

Fig. 1 Preoperative lateral abdominal radiograph (upper image) demonstrating a comminuted fracture affecting the cranial endplate of L6 with possible bone fragments within the vertebral canal and ventral to the remaining body of L6. Computed tomographic multiplanar reconstruction (MPR) sagittal (bottom left) and transverse (bottom right) plane images of the same dog, demonstrating foreshortening of the body of L6 due to a comminuted compression fracture of its cranial endplate. The cranial third of the vertebral body is completely and irregularly divided into several fragments of variable shape and size, many of which have displaced dorsally, invading the vertebral canal and causing marked compression from the ventral of the spinal cord (up to 80% of the diameter is compressed). A few large fragments are also seen ventral to the cranial aspect of the vertebra. Insert bottom left indicates the level of the transverse plane image bottom right.

Fig. 2 A smartphone digital goniometer, held by a nonsterile assistant, was used to guide advancement of a blunted 1.1-mm Kirschner wire attached to a Jacob's chuck into each pedicle at an angle of approximately 11 degrees at L7 and 50 degrees at L5. The smartphone was held at the desired angle and both the nonsterile assistant and a second scrubbed surgeon who stood further behind gave instruction to the primary surgeon to adjust the angulation of Jacob's chuck and Kirschner wire until they were parallel to the upper side of the smartphone. The dog's head is to the left of the image.

dog was anaesthetized and computed tomography (CT) from T6 to Cd1 was performed and identified a highly comminuted fracture of the vertebral body and cranial endplate of L6 with severe narrowing of the vertebral canal (►**Fig. 1**). A standard dorsal approach from L5 to sacrum was performed. Care was taken to ensure that the dog was positioned in true sternal recumbency, without obliquity. The dog was also secured cranially and caudally to the surgical table with adhesive tape. A left-sided pediculectomy was performed at L6. The cauda equina was identified and was mildly bruised. Bone fragments were removed piecemeal using a Kerrison rongeurs. Larger bone fragments were depressed ventrally with a ball probe and freer elevator. It was very challenging to depress bone fragments on the contralateral side. Once the spinal cord was deemed adequately decompressed, two towel clamps were used to apply traction to L5 and L7 to adequately reduce the minimally displaced L6 into position. Four 0.9-mm Kirschner wires were placed bilaterally across the facet joints of L5/L6 and L6/L7 (one per joint) to maintain reduction. Two 1.5-mm cortical screws were inserted bilaterally into the pedicles of L7 (one left and one right) and a further two 2.0-mm screws into the vertebral body of L5 (one left, one right) using the pedicle-probing technique.[12] Briefly, a 1.1-mm drill bit was used to remove a small area of cortex (decortication) at the site of insertion of each pedicle screw. For L7, this was at the base of its cranial articular process and for L5 in the middle (craniocaudal) of the base of the transverse process where the surface of the bone changed from a horizontal to vertical direction.[12] Following exposure of underlying cancellous bone, a smartphone digital goniometer (Smart Protractor, version 1.5.14), held by a nonsterile assistant, was used to guide advancement by the primary surgeon of a blunted 1.1-mm Kirschner wire attached to a Jacob's chuck into each pedicle/vertebral body at an angle of approximately 11 degrees at L7 and 50 degrees at L5 (►**Fig. 2**). The smartphone was held at the desired angle and both the nonsterile assistant and a second scrubbed surgeon who stood further behind gave instruction to the primary surgeon to adjust the angulation of Jacob's chuck and Kirschner wire until they were parallel to the upper side of the smartphone. Immediately prior to this, the positioning of the patient was checked to ensure there was no obliquity of the patient and that the surgical table was parallel to the operating theater floor. The specific angles of insertion at L5 and L7 were precalculated based on preoperative CT. Once a safe trajectory was established, the Kirschner wire was

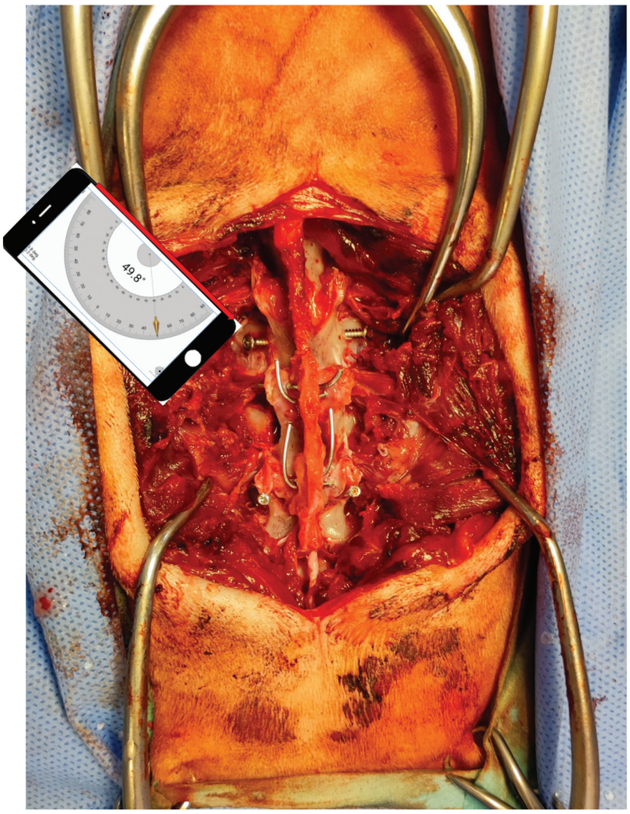

Fig. 3 Intraoperative image demonstrating placement of 1.5- to 2.0-mm screw in L5 and L7 as well as 0.9-mm Kirschner wires placed across the facet joints of L5/L6 and L6/L7. Kirschner wires have been placed across zygapophyseal joints to maintain reduction. Cranial is to the top of the image.

removed and a 1.1-mm drill bit advanced into the pedicle of L7 and the vertebral body of L5 in the same trajectory, exiting the ventral cortex. On the right side of L5, the decortication site was slightly (~2 mm) too dorsal and entry into the canal was identified with the blunted Kirschner wire and a second decortication site was created slightly (~2 mm) more ventral. The walls of all drill tracts were probed with a 0.9-mm Kirschner wire and confirmed to be intact prior to implant placement. The Kirschner wires placed across the facet joints were cut to an appropriate length and bent to allow incorporation into the PMMA (►**Fig. 3**). The surgical site was thoroughly lavaged and the PMMA applied on the dorsal aspects of the laminae and spinous processes of L5 through L7, encompassing the screw heads placed in L5 and L7 and Kirschner wires placed across the facet joints of L5/6 and L6/7. Postoperative CT identified the best-possible alignment of the floor of the vertebral canal, with improvement in spinal cord compression, although a single large compressive bone fragment remained on the side opposite the pediculectomy, as well as optimal placement of implants in L5 and L7, classified as grade 1 on the modified Zdichavsky classification[15] (►**Fig. 4**). On transverse plane images, the angle of screws placed in L7 relative to the sagittal plane was 12.4 degrees (left) and 12.5 degrees (right). The angle of screws placed at L5 was 48.0 degrees (left) and 52.0 degrees (right). The dog was treated postoperatively with intravenous fluid therapy; analgesia initially with ketamine and fentanyl constant rate infusions, transitioned later to intermittent methadone and finally buprenorphine; and cefuroxime for the first 24 hours postoperatively. The day after surgery, the dog remained nonambulatory paraparetic. It was hospitalized for 5 days postoperatively. On the day of discharge, the dog was ambulatory with mild lameness on the left pelvic limb. The dog was prescribed an 8-week period of restricted exercise, physiotherapy, and a 10-day course of paracetamol and 21-day course of gabapentin.

During a telephone follow-up 6 weeks postoperatively, the owner reported the dog's mobility to be back to normal, manifesting no signs of pain. Some difficulty with climbing stairs remained. There was mild urinary incontinence, which appeared to be improving. Faecal incontinence characterized by failure to posture and dropping of faeces from the anus was also reported. Motor function of the tail remained absent.

Repeat CT of the lumbar spine performed at 3 months postoperatively identified progression in healing of the fragmented L6 vertebral body fracture, with incomplete callus formation, less well-defined fracture fragments, and there was partial bridging of L5 and L6. There is static narrowing of the vertebral canal because of bone fragments and static positioning of PMMA and metallic implants (►**Fig. 5**). At the time of this revisit, the dog was not receiving any medication. The owner reported no limitation in the dog's mobility with regard to running, jumping, and going up stairs. Occasional episodes of inappropriate urination and defaecation in the bed and house were reported. Overall, the owner felt that the dog had awareness of impending defecation but found it difficult to control. On physical examination, there was mild lumbar epaxial muscle atrophy. There was mild staining of the fur of the pelvic limbs due to inappropriate urination. On neurological examination, paw positioning and hopping were normal in all limbs. The flexor withdrawal and myotatic reflexes were normal in the pelvic limbs. The perineal reflex was very weak to absent. The dog demonstrated wagging and lifting of the tail.

Discussion

In the past decade, smartphone goniometers have found several applications in health care, including orthopaedics, rehabilitation, neurology, occupational therapy, rheumatology, sports medicine, and paediatrics.[22–25] These applications are designed to measure angles using built-in sensors of smartphones. Numerous publications describe the use of smartphone goniometer applications to measure and assess the range of motion of joints in people.[22–25] In patients with neurological disorders, smartphone goniometers can be employed for measuring joint angles and assessing muscle spasticity or contractures. This case report describes the use of a smartphone digital goniometer combined with the freehand pedicle-probing technique to guide pedicle screw placement for repair of a comminuted L6 vertebral fracture in a 4 kg dog.

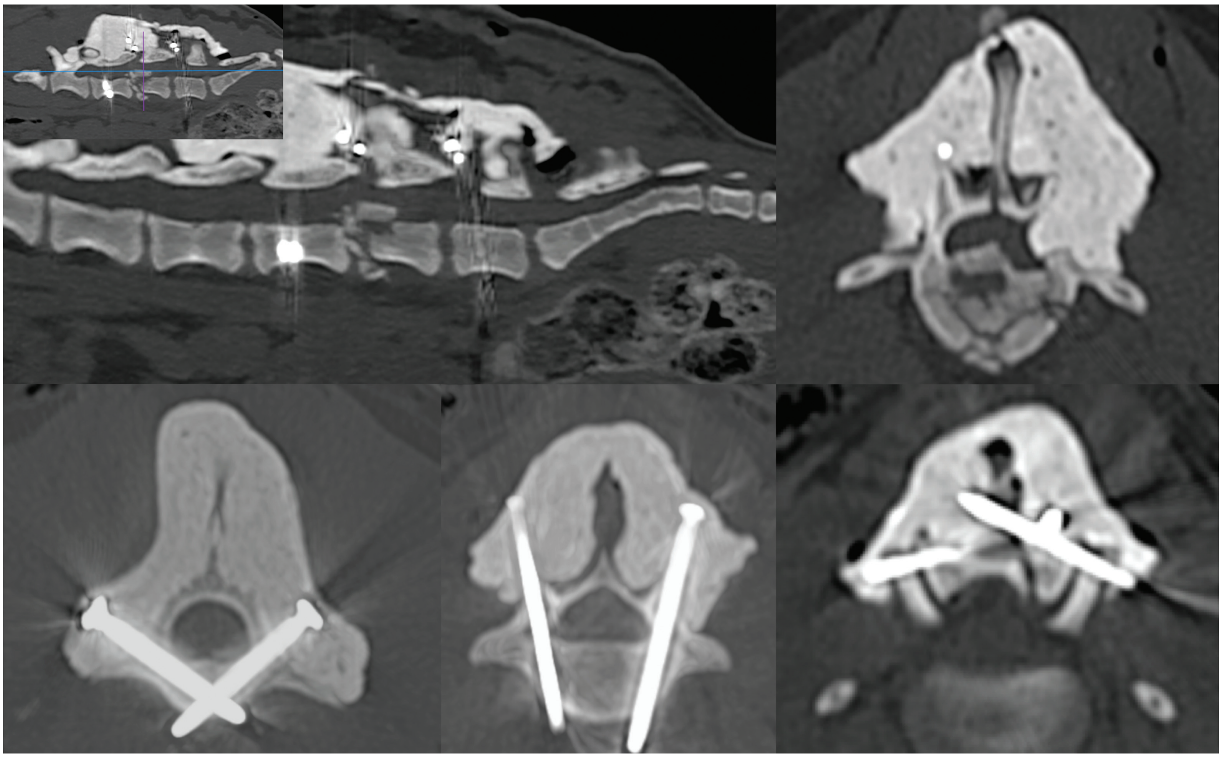

Fig. 4 Postoperative computed tomographic multiplanar reconstruction (MPR) sagittal (top left) and transverse plane images at the level of cranial L6 (top right), L5 (bottom left), L7 (bottom middle), and L6/L7 zygapophyseal joints (bottom right), demonstrating good alignment of the floor of the vertebral canal with improvement in spinal cord compression and optimal placement of implants in L5 and L7. Insert top left indicates the level of the transverse plane image top right.

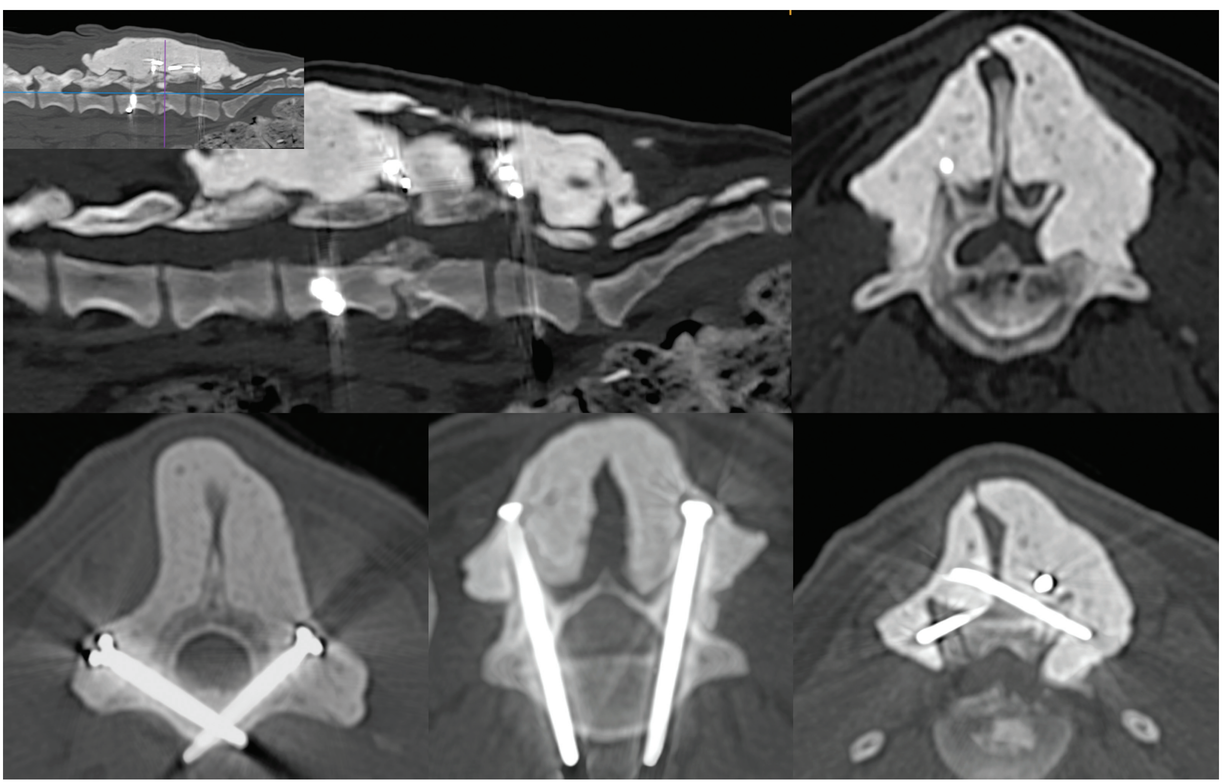

Fig. 5 Three-month postoperative computed tomographic multiplanar reconstruction (MPR) sagittal (top left) and transverse plane images at the level of cranial L6 (top right), L5 (bottom left), L7 (bottom middle), and L6/L7 zygapophyseal joints (bottom right), demonstrating progression in healing of the fragmented L6 vertebral body fracture, with incomplete callus formation, less well-defined fracture fragments, and partial bridging of L5 and L6. There is static narrowing of the vertebral canal because of bone fragments and static positioning of polymethylmethacrylate and metallic implants. Insert top left indicates the level of the transverse plane image top right.

A freehand pedicle-probing technique similar to that reported herein has been described in only two canine clinical reports[12,14] (both involving placement of screws/pins at lumbosacral joint), one *ex vivo* study involving the canine thoracolumbar vertebral column,[15] and one surgical textbook.[13] In people, the pedicle-probing technique is associated with a high degree of accuracy in several studies, even in cases with spinal deformities.[17–21,26] The freehand pedicle-probing technique does not negate the need for preoperative calculation of safe trajectories and adherence to these angles intraoperatively. This is particularly important in the L1 to L6 lumbar vertebral column because the probe has more "freedom" to travel within the vertebral body compared with the thoracic vertebral column where the probe is contained within the confines of the pedicles cortical bone. The vertically oriented pedicles of L7 also lend themselves particularly well to the pedicle-probing technique described herein.[15] Of equal importance to preoperative calculation of safe trajectories is the ability to identify intraoperatively correct screw/pin entry sites using anatomic landmarks. Similar to that observed on the right side of L5 in the case herein, if the site of decortication is only slightly too dorsal, adherence to preoperatively calculated angles could result in breach of the vertebral canal. If this does happen to occur, for example, in very small patients where the margin for error is very small, entry of a blunted Kirschner wire into the canal with the pedicle-probing technique may be associated with less injury to vertebral canal contents than a drill bit.

Although improved in comparison to preoperatively, postoperative CT identified persistent narrowing of the vertebral canal because of the presence of a single large bone fragment on the side opposite the pediculectomy. This fragment was found to be particularly challenging to reach and manipulate intraoperatively. In retrospect, depression/manipulation of this larger fragment should also have been attempted after vertebral distraction.

We have demonstrated a novel use of the smartphone goniometer to guide the correct trajectory for the advancement of the probe used as part of the probing technique. Traditional plastic or metal goniometers require careful positioning of both arms, one that is stationary and typically approximating true vertical or true horizontal, and the second that is held at the desired angle of implant placement. Smartphone goniometers use internal accelerometers that serve as position sensors. They can be calibrated to true horizontal (level) or true vertical (plumb) with a click of the screen, and once set, the surgeon needs only be concerned about the trajectory of the smartphone because the reference angle is maintained. It is vitally important while using any goniometer for spinal surgery that the patient is positioned appropriately. In our case, the smartphone was held by a nonsterile assistant, and it was crucial that the patient was positioned in true ventral recumbency without rotation/obliquity to ensure accuracy. The positioning of the surgical table also had to be confirmed, ensuring it was parallel to the operating theater floor. Instrumentation was also not performed until vertebral alignment was restored with placement of Kirschner wires across the zygapophyseal joints of L5 to L6 following distraction. Alignment was also confirmed by the alignment of the spinous processes. All these factors would have to be accounted for regardless of the type of goniometer used. If there are concerns over the positioning of the patient, the smartphone can be placed into a clear sterile bag and held directly by the surgeon.[27] In this manner, the surgeon can place the device across known symmetric anatomic landmarks such as the zygapophyseal joints in the lumbar spine and simply recalibrate the smartphone goniometer to recognize this angle as 0 degrees.

We recognize several important limitations associated with this report. This report includes only a single case. The authors used a single smartphone application that has not been validated and our results may not be replicated with other smartphone goniometer applications. Further limitations include the absence of validation of a smartphone goniometer compared with a standard goniometer and absence of assessment of accuracy of use of a smartphone goniometer held at a distance versus directly on a surface. Several studies have shown the validity and reliability of smartphone goniometer applications in assessing range of motion in the elbow, knee, and ankle in people.[22–25] A notable difference between previously reported applications of the smartphone goniometer and that employed herein is that the smartphone was in direct contact with the part of body being measured, whereas in our case, the smartphone was held from a distance by a nonsterile assistant and this could create a source of error.[22–25] The surgery was also performed by a surgeon with substantial experience in canine spine surgery, and this likely influenced the successful outcome in this case.

This report highlights that use a smartphone goniometer may be a useful adjunct to freehand pedicle-probing technique to achieve accurate implant placement in canine lumbar spine even in very small patients and may have application in other regions of the spine. Intraoperative identification of correct screw/pin entry sites using anatomic landmarks and preoperative planning remain crucial for optimal implant placement.

Conflict of Interest
None declared.

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