The effect of pedicle screw insertion through the neurocentral cartilage on the growth of immature canine vertebra

Liang Wang MD, Zhuo-jing Luo MD, Li-jing Luo MD, Lin-jie Feng MD, Hao Meng MD

1Department of Orthopaedics, No. 89 Hospital, Weifang, Shandong Province, and Departments of 2Orthopaedics and 3Radiology, Xijing Hospital, Fourth Military Medical University, Xi’an, China

Objective: To explore the influence of pedicle screw insertion through the neurocentral cartilage (NCC) on the development of vertebrae and spinal canal in an animal experiment.

Methods: Sixteen dogs were randomly assigned to three groups: in group 1, posterior muscles at the surgery site were dissected; in group 2, the pedicles were drilled through the NCC by screws; in group 3, screws were placed in the pedicles through the NCC. Vertebrae of T8, T10, T12, L2, L4 and L6 were studied with the average data of the adjacent two vertebrae serving as controls. Spiral computerized tomography (CT) was used to assess the morphologic parameters of studied vertebrae and their controls. Measurements were made by an independent radiologist on the first post-operative day and 3 months after operation. Paired Student’s t-tests of studied vertebrae and their controls were performed to evaluate the effect of pedicle screw insertion.

Results: In group 3, 3 months after operation the area, transverse diameter and anterior-posterior diameter of the vertebral canal and length of pedicle of studied vertebrae were significantly smaller than those of control vertebrae (P < 0.05). There were no significant differences in morphologic parameters between the studied vertebrae and the control vertebrae in groups 1 and 2 (P > 0.05).

Conclusion: (i) Pedicle screw placement has a significant impact on the growth of the canine vertebra canal, and may lead to iatrogenic spinal stenosis, but their placement has no significant effect on the vertebral bodies; and (ii) the NCC can repair itself automatically. Drilling pedicle bone through the NCC with a screw and then removing the screw has no obvious impact on the growth of vertebrae.

Key words: Bone screws; Cartilage; Dogs; Spine

Introduction

Because spinal deformities in children can progress to compromising cardiopulmonary functions and causing neurologic deficits, it is important to provide early surgical treatment in order to avoid long-term morbidity associated with these conditions. Surgical treatment has evolved since Harrington distraction instrumentation was introduced and popularized. Pedicle screw fixation has become one of many choices for spinal deformities in pediatric patients.

Pedicle screw fixation is currently the internal fixation method of choice for the spine of adult patients, since it enables strong fixation and offers faster fusion, without causing neurologic consequences. However, its value in young children remains undetermined. Ruf et al. reported three groups of children aged from one to six years who underwent transpedicular fixation of vertebrae for various reasons without causing neurologic complications. They found that the instrumented vertebrae developed normally in comparison to adjacent non-instrumented vertebrae, and that the procedure did not cause any neurologic deficits. They attributed the absence of both neurologic deficits and spinal stenosis to early maturity of the spinal canal; it is known that the spinal canal in humans is fully developed as young as four years of age. Hedequist et al. retrospectively investigated the use of spinal instrumentation with reduced-size in 40 patients younger than eight years with congenital spinal deformities. The complications associated with instrumentation were assessed by reviewing radiographs and...
medical records in more than three years follow-up. They found that the use of reduced-size spinal instrumentation in young patients was safe and efficacious, but it were unclear whether or not the use of instrumentation and the improvement in correction obtained in these patients would lead to a continued balanced spine with growth, and recommended longer follow-up. However, the majority of patients in previous reports were older than 4 years, by which age their spinal canals have fully developed. These observations therefore cannot be applied reliably to younger pediatric patients with immature spinal canals.

In order to evaluate the effect of pedicle screws on very young children with developing spinal canals, we designed an animal experiment with 2-month-old dogs, which are developmentally equivalent to 1–2 year old children. In our experiment, pedicle screws were placed in vertebrae in the same way as would occur in pedicle screw fixation surgery.

**Materials and methods**

The study was approved by the Ethics Committee for Experiments on Animals in our institution. Twenty-two months old domestic dogs (nine males, seven females), with body weights of 2.23 ± 0.39 kg, were assigned randomly to three groups. In group 1 (three dogs), with body weights of 2.21 ± 0.32 kg, posterior muscles at the surgery site were dissected without drilling the pedicles; in group 2 (five dogs), with body weights of 2.25 ± 0.36 kg, pedicles were drilled through the NCC but no screw was placed; in group 3 (eight dogs), with body weights of 2.23 ± 0.38 kg, pedicles were drilled through the NCC and screws were placed. In groups 2 and 3, the procedure was carried out on vertebrae T8, T10, T12, L2, L4, L6; the average data for the adjacent two vertebrae served as controls. Stainless steel screws (2.0 mm in diameter) and titanium alloy screws (3.5 mm in diameter) were used in thoracic and lumbar spines, respectively. The average transverse diameters of the NCC were approximately 4.5 mm in the thoracic spine, and 6.2 mm in the lumbar spine. Approximately 44% (thoracic spine) and 56% (lumbar spine) of the diameter of NCC was occupied by these pedicle screws.

The procedure was performed under general anesthesia after overnight fasting. After sterile preparation and draping of the surgical field, access to vertebrae T7 to L7 was achieved through a posterior midline incision to expose the transverse process tips of T8 and T10, and the transverse process roots of T12, L2, L4 and L6. In group 2, the studied vertebrae were probed by Kirschner pin (1.4 mm in diameter for thoracic vertebrae and 2.0 mm for lumbar vertebrae). After removal of the Kirschner pin, a thinner pin was used to check the tunnel, making sure that the pin didn’t involve the spine canal. Then the chosen screws were inserted into the tunnel, and subsequently removed. In group 3, the chosen screws were placed after checking the tunnel. The lengths of screws were 14 to 17 mm in thoracic vertebrae and 11 to 15 mm in lumbar vertebrae. After surgery, a spiral CT scan was performed on all subjects. If anything was wrong with the positions of screws, the operation would be redone until the positions were good.

Slices at 0.5 mm intervals were obtained with multidetector spiral CT (Aquilion/16s, Toshiba, Tokyo, Japan) to evaluate vertebral morphology with respect to the following parameters: area, transverse diameter (the widest transverse dimension) and anterior-posterior diameter of the vertebra canal (the anterior-posterior dimension at its mid line); length of pedicle (measured from a line drawn along the axis of the pedicles from the pedicle entry point to the anterior cortex of the vertebral body); transverse diameter (its widest transverse dimension), anterior-posterior diameter (the anterior-posterior dimension at its mid line) and height of vertebral body (the vertical distance between the upper and lower cortex in the lateral image, Figs. 1–4). Each vertebra from T7 to L7 was measured at three levels to determine the section with the biggest spinal canal area, at which the rest of above para-
eters were assessed. An experienced radiologist performed all measurements with the assistance of special computer software (Vitrea 2, Vital Images, Minnetonka, MN, USA).

Statistical analysis was carried out using SPSS 10.0 software. Paired Student’s t-tests were performed to evaluate the effect of pedicle screw insertion on the development of vertebrae. A P-value < 0.05 was considered statistically significant.

Results

The average weight of these dogs increased from 2.23 ± 0.39 kg to 8.50 ± 0.48 kg 3 months after surgery, and there were no differences among the three groups, which indicated that the surgery itself had no effect on the overall development of the dogs. CT imaging did not show spontaneous fusion, and no special signs of nerve injury were observed.
Tables 1 and 2 show no significant difference in all dimensional parameters between the study and control vertebrae on the first post-operative day in all three groups (16 dogs, 48 pairs of thoracic and 48 pairs of lumbar vertebrae, P > 0.05). Similar results were seen in group 1 (three dogs, nine pairs of thoracic vertebrae and nine pairs of lumbar vertebrae) and group 2 (five dogs, 15 pairs of thoracic and 15 pairs of lumbar vertebrae) at the end of the experiment. However, a reduction in several dimensions; including the area, transverse diameter and anterior-posterior diameter of the vertebral canal and length of pedicle; was observed in the instrumented in comparison to the control vertebrae in group 3 (eight dogs, 24 pairs of thoracic vertebrae and 24 pairs of lumbar vertebrae, P < 0.05) 3 months after operation. In comparison to the controls, the studied thoracic vertebrae showed approximately 10.74% narrowing of the area, 7.90% shortening of the transverse diameter and 6.12% shortening of the anterior-posterior diameter of vertebral canal; and 5.81% shortening of the length of the pedicle, 3 months after surgery. By the same time point, the studied lumbar spine showed approximately 6.38% narrowing of the area, 2.71% shortening of the transverse diameter and 5.70% shortening of the anterior-posterior diameter of the vertebral canal; and 5.36% shortening of the length of the pedicle, as compared to the control vertebrae. It appeared that other dimensional parameters such as vertebral body transverse dimensions, vertebral body anterior-posterior dimensions and height of the vertebral body remained unchanged regardless of surgery in all groups (Tables 1–4, P > 0.05).

Table 1 Comparison between studied and control vertebrae of thoracic spine (X ± s) of CT calculations from the first postoperative day

| Parameters                                | Group 1 | Group 2 | Group 3 |
|-------------------------------------------|---------|---------|---------|
|                                           | Studied vertebral | Control vertebral | Studied vertebral | Control vertebral | Studied vertebral | Control vertebral |
| Area of vertebral canal (mm²)             | 46.44 ± 6.54 | 46.78 ± 4.68 | 45.40 ± 8.87 | 48.06 ± 9.24 | 51.17 ± 8.60 | 50.42 ± 6.91 |
| Transverse diameter of vertebral canal (mm) | 7.99 ± 0.48 | 8.05 ± 0.61 | 8.19 ± 1.05 | 8.26 ± 1.04 | 9.13 ± 0.92 | 9.13 ± 1.21 |
| Anterior-posterior diameter of vertebral canal (mm) | 7.00 ± 0.75 | 6.99 ± 0.59 | 6.68 ± 0.80 | 6.77 ± 0.53 | 6.62 ± 0.86 | 6.75 ± 0.59 |
| Length of pedicle (mm)                    | 13.04 ± 0.92 | 13.21 ± 0.88 | 13.07 ± 1.12 | 13.12 ± 0.99 | 13.69 ± 1.36 | 13.63 ± 1.15 |
| Transverse diameter of vertebral body (mm) | 10.90 ± 0.51 | 10.99 ± 0.82 | 10.93 ± 1.30 | 11.13 ± 1.16 | 12.00 ± 1.43 | 11.88 ± 1.51 |
| Anterior-posterior diameter of vertebral body (mm) | 7.12 ± 0.42 | 7.27 ± 0.36 | 7.61 ± 0.93 | 7.80 ± 0.61 | 7.80 ± 0.72 | 7.67 ± 0.76 |
| Height of vertebral body (mm)             | 11.32 ± 0.83 | 11.18 ± 0.74 | 12.00 ± 1.60 | 11.78 ± 1.54 | 12.53 ± 1.39 | 12.28 ± 1.40 |

© 2009 Tianjin Hospital and Blackwell Publishing Asia Pty Ltd
Tables 1 and 2 show there were no significant differences between the studied and control vertebrae at the first postoperative day in any of the measurements; and Tables 3 and 4 show no significant differences in all measurements in group 1, which shows that studied vertebrae demonstrated no significant differences compared to the average of their neighbors naturally.

Tables 1–4 show that the studied transverse diameter, anterior-posterior diameter and height of the vertebral bodies were not significantly different from their control vertebrae in all groups, which implies that placement of pedicle screws might not retard the growth of vertebral bodies or affect the sitting height.

CT images of studied vertebrae in group 3 show differentiation of the morphology of the anterior and lateral wall of the canals as compared to controls 3 months after surgery (Figs. 1, 3), but group 2 showed no visible tunnel, or remarkable morphological differentiation (Figs. 2, 4).

### Discussion

The NCC, a type of physis with a bipolar arrangement histologically, is mainly responsible for the growth of the posterior elements of vertebrae\(^\text{10-13} \). It is damaged in surgery involving pedicle screw fixation. Therefore, pedicle screw fixation would presumably affect spinal canal development by damaging the NCC, and likely result in spinal canal stenosis, if used in pediatric patients. However, there are few reports of patient or animal studies which address this issue. An answer to the question has

---

**Table 3** Comparison between studied and control vertebrae of thoracic spine (\( \bar{x} \pm s \)) of CT calculations from 3 months after operation

| Parameters                                           | Group 1 | Group 2 | Group 3 |
|------------------------------------------------------|---------|---------|---------|
|                                                     | Studied vertebrae | Control vertebrae | Studied vertebrae | Control vertebrae | Studied vertebrae | Control vertebrae |
| Area of vertebral canal (mm\(^2\))                   | 54.22 ± 16.21 | 54.06 ± 13.72 | 50.47 ± 9.65 | 50.60 ± 10.67 | 47.88 ± 9.13* | 54.73 ± 10.69 |
| Transverse diameter of vertebral canal (mm)          | 8.60 ± 0.103 | 8.71 ± 0.65 | 8.61 ± 0.51 | 8.51 ± 0.17 | 8.70 ± 0.71* | 9.54 ± 1.01 |
| Anterior-posterior diameter of vertebral canal (mm)  | 8.31 ± 1.28 | 8.36 ± 1.34 | 7.27 ± 0.50 | 7.33 ± 0.47 | 7.20 ± 0.97* | 7.73 ± 0.74 |
| Length of pedicle (mm)                               | 18.76 ± 3.78 | 19.03 ± 1.16 | 16.57 ± 1.97 | 16.74 ± 1.74 | 15.97 ± 1.58* | 16.58 ± 1.75 |
| Transverse diameter of vertebral body (mm)           | 11.77 ± 2.10 | 12.46 ± 2.51 | 11.15 ± 1.57 | 11.05 ± 1.56 | 11.55 ± 1.43 | 11.26 ± 1.46 |
| Anterior-posterior diameter of vertebral body (mm)   | 8.82 ± 0.062 | 8.90 ± 0.50 | 7.85 ± 0.81 | 7.82 ± 0.71 | 7.90 ± 1.10 | 8.11 ± 0.94 |
| Height of vertebral body (mm)                         | 13.48 ± 2.42 | 12.98 ± 2.72 | 10.37 ± 1.34 | 10.27 ± 1.26 | 10.83 ± 1.90 | 10.74 ± 1.63 |

Note: *\( P < 0.05 \).

**Table 4** Comparison between studied and control vertebrae of lumbar spine (\( \bar{x} \pm s \)) of CT calculations from 3 months after operation

| Parameters                                           | Group 1 | Group 2 | Group 3 |
|------------------------------------------------------|---------|---------|---------|
|                                                     | Studied vertebrae | Control vertebrae | Studied vertebrae | Control vertebrae | Studied vertebrae | Control vertebrae |
| Area of vertebral canal (mm\(^2\))                   | 62.00 ± 12.22 | 61.67 ± 13.16 | 58.07 ± 12.34 | 60.87 ± 9.08 | 57.59 ± 15.15* | 61.02 ± 12.14 |
| Transverse diameter of vertebral canal (mm)          | 9.28 ± 1.08 | 9.18 ± 1.35 | 9.42 ± 1.27 | 9.49 ± 1.09 | 9.49 ± 1.17* | 9.76 ± 1.09 |
| Anterior-posterior diameter of vertebral canal (mm)  | 7.84 ± 0.86 | 7.68 ± 0.82 | 8.00 ± 0.64 | 8.02 ± 0.60 | 7.50 ± 0.90* | 7.95 ± 0.71 |
| Length of pedicle (mm)                               | 14.58 ± 1.37 | 14.56 ± 1.29 | 13.47 ± 1.35 | 13.80 ± 1.44 | 13.48 ± 1.17* | 14.28 ± 1.33 |
| Transverse diameter of vertebral body (mm)           | 13.62 ± 2.44 | 13.65 ± 2.41 | 12.04 ± 1.77 | 12.01 ± 2.17 | 12.76 ± 1.60 | 12.49 ± 1.26 |
| Anterior-posterior diameter of vertebral body (mm)   | 9.01 ± 1.31 | 9.26 ± 0.53 | 8.16 ± 0.80 | 8.24 ± 0.83 | 8.46 ± 0.88 | 8.23 ± 0.04 |
| Height of vertebral body (mm)                         | 17.68 ± 3.20 | 17.46 ± 3.35 | 13.29 ± 0.99 | 12.95 ± 1.28 | 14.39 ± 2.11 | 14.29 ± 1.87 |

Note: *\( P < 0.05 \).
profound clinical significance in treating spinal deformities in very young pediatric patients. In our experiment, we have produced convincing evidence that pedicle fixation can lead to spinal canal stenosis in pediatric patients so young that their spinal canals are not yet fully developed.

Damage to the NCC is chiefly caused by two key steps of the procedure: drilling the pedicles, and placement of the pedicle screws. However it is not clear which one of them plays the more important role in causing spinal canal stenosis, as shown in Tables 3 and 4. Campbell et al. have reported that drilling a hole across the growth plate of a long bone in an immature dog does not necessarily result in growth retardation unless a large bone bridge across the physis occurs. Similar to this report, we did not observe significant differences in dimensions of studied and control vertebrae, such as length of pedicle and area of vertebra canal, even though approximately 50% of the NCC was damaged by screw drilling (group 2, see Tables 3, 4), which suggested that screw drilling does not affect vertebral development.

Removal of screws should be undertaken as early as possible. A large caliber screw presumably causes more severe damage to NCC, and thus poses a greater risk for acute or chronic neurologic complications. However, the precise relation between the size of the pedicle screw and the effect on vertebral growth remains to be defined. The pediatric pedicle possesses remarkable viscoelastic properties, which can allow an almost 200% increase in internal diameter before structural failure occurs.

This observation indicates that thicker screws, which usually provide greater strength and stability, could be well tolerated without damaging the vertebrae. This appears to be true also in our experiment, as we saw no significant morphological changes in vertebrae upon completion of surgery in all 3 groups, although we chose larger caliber pedicle screws to perform pedicle fixation. Our observation suggests that large caliber screws do not impede development of the vertebral body in very young dogs.

In a study over 4 months with nine immature pigs in which the lumbar vertebrae on one side were studied with the other side as controls, Cil et al. showed that whether or not compression is applied across the physis of the vertebrae, approximately 4% to 9% shortening of pedicle lengths and 20% to 26% narrowing of the hemi-canal areas results. Clearly, pedicle screws carry a risk of iatrogenic spinal stenosis in very young pigs. Although side-to-side comparison may have less variation, influences of one side on the other are unavoidable. And, if the CT scan planes were not perfectly vertical to the spine, the calculations would lead to an erroneous result.

In summary, pedicle screw placement had significant impact on the growth of the immature canine spine canal, and led to iatrogenic spinal stenosis, but had no evident influence on the development of the vertebral body. Caution should be exercised when attempting to relate the current results to children, since the dog is not bipedal, and shares little anatomic similarity with humans.

**Acknowledgment**

The authors express their thanks to Dr Chang-cheng Zhu, Department of Pathology, Jack D. Weiler Hospital of the Albert Einstein College of Medicine, Montefiore Medical Center, New York, NY, USA for their assistance in the preparation of this manuscript.

**Disclosure**

The experiments comply with the current laws of China in having been performed with ethics approval.

**References**

1. Wiggins GC, Shaffrey CI, Abel MF, et al. Pediatric spinal deformities. Neurosurg Focus, 2003, 14: e3.
2. Barr SJ, Schuette AM, Emans JB. Lumbar pedicle screws versus hooks. Results in double major curves in adolescent idiopathic scoliosis. Spine, 1997, 22: 1369–1379.
3. Dobbs MB, Lenke LG, Kim YJ, et al. Selective posterior thoracic fusions for adolescent idiopathic scoliosis: comparison of hooks versus pedicle screws. Spine, 2006, 31: 2400–2404.
4. Kim YJ, Lenke LG, Cho SK, et al. Comparative analysis of pedicle screw versus hook instrumentation in posterior spinal fusion of adolescent idiopathic scoliosis. Spine, 2004, 29: 2040–2048.
5. Porter RW, Pavitt D. The vertebral canal: I. Nutrition and development, an archaeological study. Spine, 1987, 12: 901–906.
6. Ruf M, Harms J. Pedicle screws in 1- and 2-year-old children: technique, complications, and effect on further growth. Spine, 2002, 27: E460–E466.
7. Ruf M, Harms J. Posterior hemivertebra resection with transpedicular instrumentation: early correction in children aged 1 to 6 years. Spine, 2003, 28: 2132–2138.
8. Ruf M, Jensen R, Jeszenszky D, et al. Hemivertebra resection in congenital scoliosis—early correction in young children. Z Orthop Ihre Grenzgeb, 2006, 144: 74–79.
9. Hedequist DJ, Hall JE, Emans JB. The safety and efficacy of spinal instrumentation in children with congenital spine deformities. Spine, 2004, 29: 2081–2087.
10. Cañadell J, Beguiristain JL, Gonzalez Iturri J, et al. Some aspects of experimental scoliosis. Arch Orthop Trauma Surg, 1978, 93: 75–85.
11. Knutsson F. Vertebral genesis of idiopathic scoliosis in children. Acta Radiol Diagn (Stockh), 1966, 4: 395–402.
12. Maat GJ, Matricali B, van Persijn van Meerten EL. The neurocentral vertebral cartilage: anatomy, physiology and physiopathology. Spine, 1996, 21: 661–666.
13. Vital JM, Beguiristain JL, Algara C, et al. The neurocentral vertebral cartilage: anatomy, physiology and physiopathology. Surg Radiol Anat, 1989, 11: 323–328.
14. Campbell CJ, Grisolia A, Zanconato G. The effects produced in the cartilaginous epiphyseal plate of immature dogs by experimental surgical traumata. J Bone Joint Surg Am, 1959, 41: 1221–1242.
15. Guzzanti V, Falciglia F, Gigante A, et al. The effect of intra-articular ACL reconstruction on the growth plates of rabbits. J Bone Joint Surg Br, 1994, 76: 960–963.
16. Janarv PM, Wikström B, Hirsch G. The influence of transphyseal drilling and tendon grafting on bone growth: an experimental study in the rabbit. J Pediatr Orthop, 1998, 18: 149–154.
17. Patrick C, Anthony SR, Alexander G, et al. Thoracic pedicle expansion after pedicle screw insertion in a pediatric cadaveric spine: a biomechanical analysis. Spine, 2004, e4 (Suppl. 1): S93.
18. Cil A, Yazici M, Daglioglu K, et al. The effect of pedicle screw placement with or without application of compression across the neurocentral cartilage on the morphology of the spinal canal and pedicle in immature pigs. Spine, 2005, 30: 1287–1293.