X-Ray assessment of the effect of pedicle screw on vertebra and spinal canal growth in children before the age of 7 years

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Abstract

Purpose To determine the reliability of pedicle screws placed in children younger than 7 years of age, and to evaluate the effect of pedicle screw insertion on further growth of the vertebra and spinal canal.

Methods A retrospective study of 35 consecutive patients through Jan 2003–Dec 2010 for congenital scoliosis in <7 years children was performed at one spine center. Patients undergoing pedicle screw instrumentation of at least two levels, which had been followed-up for at least 24 months were included. Measurements were performed in instrumented and adjacent non-instrumented levels. The effect of pedicle screw insertion on further growth was evaluated.

Results The average age at surgery was 4.4 year (53 months, range, 23–84 months). 190 segments in 35 patients met the inclusion criteria. 77 segments had no screws and 113 had at least one screw. There was a significant difference between the pre-operative and final follow-up values of the measurement of spinal canal and vertebral body parameters ($P < 0.001$). No significant difference existed between growth rates of vertebral bodies and the sagittal diameters of spinal canal with or without screws. The growth rates of vertebral bodies in lumbar spine were higher than in thoracic spine in both instrumented and adjacent groups.

Conclusion Pedicle screw instrumentation does not cause a retardation effect on the development of vertebral bodies

and the spinal canal in children at an early age. It is a safe and reliable procedure to achieve a stable fixation.

Keywords Pediatric scoliosis · Pedicle screws · Spinal growth · Transpedicular instrumentation

Introduction

Pedicle screws are widely used in spinal surgery. There is an extensive published literature concerning the use of pedicle screw instrumentation for spinal surgery in adults [1–6]. Pedicle screws, which allow for three-column fixation of the vertebral body, have shown superior biomechanical properties over other instrumentation techniques of the spine [1, 2]. Pedicle screw constructs can provide greater correction of spinal deformities over hook constructs [3–6]. Recently, there is a trend to use pedicle screws in pediatric patients with spinal disorders, including the very young children.

However, there are special concerns surrounding the use of pedicle screws in very young children, including spinal canal stenosis by early closure of the neurocentral cartilage (NCC), availability of appropriate-sized instrument, and migration of screws during skeletal growth and development [7]. The NCC is the bipolar growth plate that is thought to contribute to the growth of the spinal canal and the pedicle in the young children [8–10]. In previous studies, both anatomical and radiological, the age at which the NCC closes has been reported to be between 5 and 16 years [11, 12]. In immature animals experiment, it has been shown that vertebral growth is retarded by inhibition of the NCC. The pedicle screws have an influence in development on symmetry and canal parameters [13–15]. The consistent findings of negative effects imparted upon

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pedicle growth in these previous animal studies have increased the concerns that pedicle screws used in young children might result in similar problems.

Its contribution to spinal growth in humans during the postnatal period remains unclear. In prior studies, many authors have analyzed the anatomy and morphology of pedicles in the thoracic spine and reported on the safety and efficacy of pedicle screw placement in adolescents [16–19]. There have been few reports regarding the effect of pedicle screws on pedicle, vertebra and spinal canal of pediatric patients with spinal deformities, especially in very young children [20–22]. The purpose of this study was to determine the reliability of pedicle screws placed in children <7 years of age, and to evaluate the effect of pedicle screw insertion on further growth of the vertebra and spinal canal at a minimum follow-up of 2 years.

Methods

With the approval of the institution's Institutional Review Board, 35 consecutive patients younger than 7 years of age were treated with 212 pedicle screws placed for congenital scoliosis from January 2003 to December 2010 at a single spine center. There were 16 boys and 19 girls. The average age at the initial surgery was 4.4 year (53 months, range, 23–84 months). Diagnoses were congenital scoliosis or kyphoscoliosis, which were due to hemivertebra, wedge vertebra or butterfly vertebra.

The techniques for pedicle screw implantation in very young children

Generally speaking, it is relatively easy in placing a pedicle screw in the lumbar region, with the entry point at the base of transverse process and the lateral border of the superior articular facet. However, that is not the case in the small diameter of the thoracic pedicle, which is technically demanding. In present study, the starting point was determined using the free-hand thoracic pedicle screw insertion method introduced by Suk et al. [18]. The direction of inserting the screw was identified by referring to the transverse angle of screw insertion direction based on pre-operative CT scan.

After determining the position of the ideal pedicle entry points and the direction of the pedicle paths, the pedicle was entered through the point with a 2-mm diameter drill. Then a blunt-ended probe was used to palpate five distinct bony borders: a floor and four walls (medial, lateral, superior, and inferior). A safe pedicle tract could be confirmed when the probe met bony resistance in all directions and cancellous bone at the tip, meaning that the hole was

globally surrounded by bone. Then a 3.0- or 3.5-mm diameter pedicle screw was placed into the pedicle, and the diameter of screw was gradually enlarged in 0.5-mm increments to expand the screw tract. For every increase of the diameter of the screw, the differences in handling sense should be meticulously comprehended in the process of placing the screw slowly down the pedicle into the body, and then draw it back, and palpate the tract with a probe to make sure that the five osseous borders were intact. Two methods helped to determine the screw length during the operation: the length of the probe when it touched but not perforated the cortex of the anterior vertebra body in the operation, and the depth from the starting point to the anterior of vertebra body measured by CT scan before the operation. The instruments were from CDH, USS, and Moss-Miami.

The children with standing long cassette anterior–posterior and lateral radiographs at pre-operation, immediately after surgery and final follow-up were included. Segments were divided into instrumented and non-instrumented levels (upper and lower adjacent vertebra). The measurements performed on all follow-ups, available preoperative and immediately post-operation radiograph data were as follows (Fig. 1):

In the lateral view:

The upper and lower length of the vertebral bodies (L1 and L2);

The anterior and posterior height of the vertebral bodies (H1 and H2);

Area 1: The area of the vertebral body in lateral projection was estimated by multiplication of the average length and height.

The distance from the tips of the screws to the anterior cortex of the vertebral body (TCD);

The anterior–posterior diameters of spinal canal: distance from the posterior cortex of the vertebral body to the lamina (CAP);

The height of intervertebral space (HIS);

In the posteroanterior view:

The upper and lower width of the vertebral bodies (W1 and W2);

The left and right height of the vertebral bodies (H1 and H2);

Area 2: The area of the vertebral body in posteroanterior projection was estimated by multiplication of the average width and height.

The height of pedicle projection (PH);

The distance of bilateral pedicle medial (BMPD) and lateral (BLPD).

Radiographic measurements were manually obtained by two surgeons using a double-blind method, and the mean

Fig. 1 Demonstration of measurements performed on the posteroanterior (*left*) and lateral view (*right*) X-ray of a patient. *W1* and *W2*: the upper and lower width of the vertebral bodies; *H1* and *H2*: the left and right height of the vertebral bodies; *PH* the height of pedicle projection, *BMPD* the distance of bilateral pedicle medial, *BLPD* the distance of bilateral pedicle lateral, *L1* and *L2* the upper and lower

length of the vertebral bodies, *H1* and *H2* the anterior and posterior height of the vertebral bodies, *TCD* the distance from the tips of the screws to the anterior cortex of the vertebral body, *CAP* the anterior–posterior diameters of spinal canal: distance from the posterior cortex of the vertebral body to the lamina, *HIS* the height of intervertebral space

Fig. 2 Demonstration of measurements performed on the pre-operative (*left*) and final follow-up (*right*) computed tomographic images of a patient. The patient, a 115-month-old boy at follow-up, had been operated on at the age of 35 months. *PL* indicates pedicle length; *PW*

indicates pedicle width, *VAP* indicates vertebral body length, *CAP* anterior–posterior diameter of the spinal canal, *CLAT* interpedicular diameter of the spinal canal

value was used. The magnification was eliminated by comparison with the well-known size of the metal implants. The size of the instrumented vertebrae and the upper and lower adjacent vertebrae were compared at pre-operation, immediately after surgery and final follow-up.

Pedicles were divided into groups according to whether they had screw or not, including no screw, unilateral and bilateral screws. The adjacent vertebrae were divided into the inside and outside of fusion level. A factor of growth for each vertebra was calculated. Segments were also

divided into thoracic and lumbar groups to determine whether vertebral level played a role in the amount of growth.

In total, 4 of the 35 patients had post-operative CT scans in final follow-up, which aim to evaluate the spinal fusion status. The measurements performed on all follow-up and available pre-operative CT axial images were as follows: anterior–posterior vertebral body length (VAP), left and right pedicle lengths (PL), left and right pedicle width (PW), anterior–posterior diameter of the spinal canal (CAP) and interpedicular diameter of the spinal canal (CLAT) (Fig. 2).

Measurements were compared between them. For statistical analysis, the change in measurements (Δ representing growth) was calculated by subtraction of pre-operative measurements from final follow-up measurements. In addition, the parameters measured by CT scan images and X-ray were compared to determine the reliability of plain radiograph.

The dependent samples *T* tests and ANOVA test to analyze the differences between each comparison. SPSS version 17.0 (SPSS Inc., Chicago, IL, USA) was used for all statistical analyses. *P* values <0.05 were considered statistically significant.

Table 1 Patient characteristics

Case no.	Sex	Age (mon)	Deformity	Level	Screws location	Follow-up time (mon)
1	M	23	HV:T6/7 and T11	T6–7, T10–12	T6, T7, T10, T12	42
2	F	23	HV:T12/L1	T11–L2	T11, T12, L1, L2	61
3	M	32	HV:T12 and L3	T11–L1, L2–4	T11, L1, L2, L4	40
4	F	83	HV:T12	T8–L4	T8, T9, T10, L2, L3, L4	41
5	M	33	HV:T11	T10–12	T10, T12	82
6	F	35	HV:L2	L1–L3	L1, L3	80
7	F	81	HV:T5 and T8	T12–L2	T12, L2	47
8	M	59	HV:L1	T11–L3	T11, T12, L2, L3	69
9	F	71	HV:L2/3	T9–L4	T9, T10, L3, L4	25
10	M	40	HV:T9/10	T9–10	T9, T10	34
11	M	24	BV:T9	T6–L3	T6, T7, T10, L1, L2, L3	68
12	M	42	HV:T10/11	T9–12	T9, T10, T11, T12	45
13	F	46	HV:T9	T5–11	T5, T6, T10, T11	75
14	F	23	HV:T5	T3–8	T3, T4, T6, T7, T8	86
15	F	60	HV:T8	T5–12	T5, T7, T9, T10, T11, T12	41
16	F	27	HV:L3	L2–4	L2, L4	44
17	M	73	HV:T7 and T10	T6–11	T6, T8, T9, T11	93
18	F	71	HV:T10	T8–12	T8, T9, T11, T12	49
19	F	51	HV:L2	L1–L3	L1, L3	39
20	F	47	HV:L2	L1–L3	L1, L3	71
21	F	72	HV:T11	T8–L3	T8, L3	31
22	M	23	CS	T7–L3	L2, L3	25
23	M	35	HV:T11	T9–L1	T9, T10, T12, L1	41
24	F	72	WV:L1	T10–L4	T10, T11, L2, L3, L4	88
25	M	65	HV:L1	T12–L2	T12, L2	97
26	F	81	WV:T12, BV:L1	T9–L3	T9, T11, T12, L2, L3	29
27	M	34	HV:T11/12	T11–12	T11, T12	30
28	M	37	HV:L4/5	L4–L5	L4, L5	26
29	F	83	CS:SF	T8–L4	T8, T9, T11, L2, L3, L4	31
30	F	49	HV:L2 and L4/5	L2–5	L2, L4, L5	70
31	M	84	HV:L3/4	L3–L4	L3, L4	76
32	M	61	HV:T12	T10–L1	T10, T11, L1	46
33	M	42	HV:T12/L1	T11–L2	T11, L2	49
34	F	62	HV:T10/11	T9–L1	T9, T12, L1	34
35	M	72	HV:T11	T8–L1	T8, T12, L1	26

HV hemivertebra, WV wedge vertebra, BV butterfly vertebra, CS congenital scoliosis, SF failure of segmentation, mon month

Table 2 Number of screws placed per level

Screws	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	L1	L2	L3	L4	L5
Bilateral	1	1	1	2	4	6	9	9	11	13	9	12	14	6	1
Unilateral	0	0	0	2	1	0	2	2	2	1	1	2	0	1	0
Total	1	1	1	4	5	6	11	11	13	14	10	14	14	7	1

Table 3 (a) All levels without screws (S[−]) compared with screws (S[+ +]). (b) All the levels were selected, thoracic levels (T) were compared with lumbar levels (L) for growth

Measurements (cm)	Pre-operation (average)		Last follow-up (average)		Δ (average)		P (between Δ)
	S (−)	S (+ +)	S (−)	S (+ +)	S (−)	S (+ +)	
(a)							
L (lateral)	2.00 ± 0.44	1.94 ± 0.38	2.57 ± 0.66	2.42 ± 0.54	0.57 ± 0.39	0.48 ± 0.34	0.091
H (lateral)	1.47 ± 0.43	1.41 ± 0.39	1.91 ± 0.59	1.80 ± 0.52	0.45 ± 0.35	0.40 ± 0.29	0.255
Area 1	3.08 ± 1.61	2.85 ± 1.34	5.22 ± 2.99	4.58 ± 2.43	2.14 ± 1.80	1.73 ± 1.41	0.094
CAP	1.35 ± 0.23	1.34 ± 0.23	1.55 ± 0.30	1.53 ± 0.34	0.20 ± 0.25	0.19 ± 0.25	0.703
W (P-A)	2.05 ± 0.54	2.02 ± 0.40	2.14 ± 0.62	1.83 ± 0.74	0.10 ± 0.51	0.23 ± 0.38	0.068
H (P-A)	3.12 ± 0.80	3.09 ± 0.59	3.56 ± 1.07	3.03 ± 0.94	0.43 ± 0.65	0.28 ± 0.27	0.415
Area 2	3.12 ± 0.74	3.14 ± 0.64	3.71 ± 1.03	3.49 ± 0.86	0.54 ± 0.67	0.36 ± 0.64	0.106
HIS (P-A)	1.34 ± 0.35	1.32 ± 0.34	1.79 ± 0.53	1.69 ± 0.58	0.43 ± 0.67	0.38 ± 0.42	0.043
HIS (lateral)	4.34 ± 1.90	4.27 ± 1.76	7.05 ± 3.81	6.30 ± 3.62	2.63 ± 2.50	2.02 ± 2.26	0.034
Measurements (cm)	Pre-operation (average)		Last follow-up (average)		Δ (average)		P (between Δ)
	T	L	T	L	T	L	
(b)							
L (lateral)	1.87 ± 0.36	2.09 ± 0.42	2.35 ± 0.57	2.64 ± 0.60	0.49 ± 0.36	0.55 ± 0.36	0.210
H (lateral)	1.24 ± 0.29	1.68 ± 0.40	1.61 ± 0.45	2.16 ± 0.52	0.37 ± 0.30	0.48 ± 0.33	0.018
Area 1	2.41 ± 1.04	3.65 ± 1.60	3.99 ± 2.18	5.95 ± 2.87	1.59 ± 1.41	2.30 ± 1.72	0.002
CAP	1.33 ± 0.23	1.36 ± 0.24	1.52 ± 0.35	1.56 ± 0.29	0.19 ± 0.26	0.20 ± 0.24	0.699
BMPD-A	1.82 ± 0.32	2.33 ± 0.46	1.83 ± 0.54	2.43 ± 0.61	0.15 ± 0.47	0.07 ± 0.54	0.527
BLPD-A	2.80 ± 0.50	3.50 ± 0.70	3.01 ± 0.93	4.10 ± 0.90	0.33 ± 0.75	0.50 ± 0.43	0.096
W (P-A)	2.87 ± 0.57	3.48 ± 0.66	3.23 ± 0.82	4.06 ± 0.87	0.38 ± 0.60	0.50 ± 0.72	0.227
H (P-A)	1.21 ± 0.29	1.48 ± 0.35	1.50 ± 0.44	2.04 ± 0.56	0.30 ± 0.33	0.52 ± 0.45	0.000
Area 2	3.59 ± 1.52	5.23 ± 1.75	5.13 ± 2.72	8.60 ± 3.94	1.57 ± 1.77	3.20 ± 2.99	0.000
HIS (P-A)	0.35 ± 0.12	0.46 ± 0.20	0.39 ± 0.21	0.60 ± 0.36	0.04 ± 0.19	0.10 ± 0.32	0.141
HIS (lateral)	0.40 ± 0.17	0.57 ± 0.24	0.41 ± 0.19	0.72 ± 0.27	0.02 ± 0.17	0.14 ± 0.25	0.000
PH-L	0.62 ± 0.23	0.79 ± 0.19	0.78 ± 0.25	1.09 ± 0.27	0.22 ± 0.25	0.30 ± 0.22	0.120
PH-R	0.64 ± 0.23	0.73 ± 0.23	0.76 ± 0.28	1.06 ± 0.27	0.20 ± 0.16	0.30 ± 0.20	0.055

Results

The detail demographic data are summarized in Table 1. At follow-up, the patients' ages were between 49 and 167 months (average 105.3 months). The follow-up duration for the patients was a minimum of 25 months, maximum of 97 months, and an average of 52.3 months. The pedicle screw instrumentation was performed for growing rod instrumentation (1 patient), posterior instrumentation and fusion (15 patients), hemivertebrectomy, and short-

segment instrumentation and fusion (19 patients). For 33 of the patients, the pedicle screw instrumentation was the first surgical intervention in the area of the spine; the remaining two had surgery performed around the spine that did not include fusion and/or pedicle screw instrumentation.

A total of 190 segments in patients with pre-operative images met the inclusion criteria and were measured. 77 segments had no screws, and 113 had at least one screw. 99 had bilateral screws, and 14 had unilateral screws (5 right and 9 left). The location of the involved vertebrae was

Table 4 (a) Only the levels with screws were selected. Thoracic levels (T) were compared with lumbar levels (L) for growth. (b) Only the levels without screws were selected. Thoracic levels (T) were compared with lumbar levels (L)

Measurements (cm)	Pre-operation (average)		Last follow-up (average)		Δ (average)		P (between Δ)
	T	L	T	L	T	L	
(a)							
L (lateral)	1.86 $\pm$ 0.35	2.06 $\pm$ 0.39	2.32 $\pm$ 0.54	2.57 $\pm$ 0.52	0.46 $\pm$ 0.35	0.51 $\pm$ 0.31	0.422
H (lateral)	1.25 $\pm$ 0.30	1.65 $\pm$ 0.39	1.60 $\pm$ 0.45	2.11 $\pm$ 0.48	0.35 $\pm$ 0.30	0.46 $\pm$ 0.27	0.052
Area 1	2.41 $\pm$ 1.05	3.52 $\pm$ 1.45	3.89 $\pm$ 2.16	5.62 $\pm$ 2.47	1.49 $\pm$ 1.38	2.10 $\pm$ 1.39	0.021
CAP	1.34 $\pm$ 0.24	1.33 $\pm$ 0.23	1.51 $\pm$ 0.37	1.55 $\pm$ 0.29	0.17 $\pm$ 0.27	0.22 $\pm$ 0.23	0.289
W (P-A)	1.84 $\pm$ 0.27	2.31 $\pm$ 0.40	1.59 $\pm$ 0.67	2.38 $\pm$ 0.67	0.22 $\pm$ 0.15	0.26 $\pm$ 0.80	0.407
H (P-A)	2.84 $\pm$ 0.45	3.46 $\pm$ 0.61	2.59 $\pm$ 0.83	3.90 $\pm$ 0.29	0.25 $\pm$ 0.18	0.36 $\pm$ 0.51	0.000
Area 2	2.95 $\pm$ 0.57	3.44 $\pm$ 0.63	3.23 $\pm$ 0.82	3.89 $\pm$ 0.78	0.32 $\pm$ 0.68	0.42 $\pm$ 0.58	0.000
HIS (P-A)	1.22 $\pm$ 0.29	1.47 $\pm$ 0.34	1.46 $\pm$ 0.45	2.05 $\pm$ 0.58	0.26 $\pm$ 0.36	0.56 $\pm$ 0.44	0.766
HIS (lateral)	3.70 $\pm$ 0.55	5.15 $\pm$ 1.71	5.02 $\pm$ 2.69	8.35 $\pm$ 3.98	1.34 $\pm$ 1.76	3.10 $\pm$ 2.99	0.001
TCD ^a	0.35 $\pm$ 0.12	0.46 $\pm$ 0.20	0.38 $\pm$ 0.21	0.56 $\pm$ 0.31	0.03 $\pm$ 0.18	0.04 $\pm$ 0.29	0.198
(b)							
L (lateral)	1.88 $\pm$ 0.39	2.13 $\pm$ 0.45	2.42 $\pm$ 0.62	2.74 $\pm$ 0.68	0.54 $\pm$ 0.37	0.61 $\pm$ 0.41	0.434
H (lateral)	1.23 $\pm$ 0.29	1.72 $\pm$ 0.42	1.64 $\pm$ 0.46	2.22 $\pm$ 0.58	0.40 $\pm$ 0.30	0.50 $\pm$ 0.39	0.208
Area 1	2.41 $\pm$ 1.05	3.82 $\pm$ 1.79	4.17 $\pm$ 2.25	6.36 $\pm$ 3.29	1.63 $\pm$ 1.45	2.55 $\pm$ 2.06	0.027
CAP	1.30 $\pm$ 0.20	1.39 $\pm$ 0.25	1.53 $\pm$ 0.31	1.57 $\pm$ 0.30	0.22 $\pm$ 0.25	0.18 $\pm$ 0.26	0.727
BMPD	1.78 $\pm$ 0.38	2.36 $\pm$ 0.54	1.89 $\pm$ 0.51	2.44 $\pm$ 0.62	0.14 $\pm$ 0.50	0.06 $\pm$ 0.54	0.600
BLPD	2.74 $\pm$ 0.59	3.54 $\pm$ 0.81	3.09 $\pm$ 0.94	4.12 $\pm$ 0.94	0.33 $\pm$ 0.34	0.51 $\pm$ 0.43	0.073
W (P-A)	2.74 $\pm$ 0.55	3.52 $\pm$ 0.69	3.21 $\pm$ 0.84	4.26 $\pm$ 0.95	0.45 $\pm$ 0.42	0.59 $\pm$ 0.87	0.386
H (P-A)	1.20 $\pm$ 0.28	1.49 $\pm$ 0.36	1.57 $\pm$ 0.43	2.02 $\pm$ 0.53	0.37 $\pm$ 0.26	0.48 $\pm$ 0.46	0.177
Area 2	3.40 $\pm$ 1.36	5.33 $\pm$ 1.81	5.34 $\pm$ 2.80	8.91 $\pm$ 3.93	1.98 $\pm$ 1.69	3.31 $\pm$ 3.02	0.013
HIS (P-A)	0.35 $\pm$ 0.12	0.46 $\pm$ 0.19	0.41 $\pm$ 0.22	0.66 $\pm$ 0.41	0.06 $\pm$ 0.20	0.18 $\pm$ 0.35	0.063
HIS (lateral)	0.38 $\pm$ 0.16	0.61 $\pm$ 0.22	0.45 $\pm$ 0.18	0.78 $\pm$ 0.26	0.07 $\pm$ 0.18	0.16 $\pm$ 0.24	0.091
PH-L	0.63 $\pm$ 0.23	0.80 $\pm$ 0.19	0.78 $\pm$ 0.25	1.08 $\pm$ 0.27	0.21 $\pm$ 0.14	0.29 $\pm$ 0.22	0.152
PH-R	0.63 $\pm$ 0.23	0.74 $\pm$ 0.23	0.76 $\pm$ 0.28	1.06 $\pm$ 0.28	0.19 $\pm$ 0.16	0.29 $\pm$ 0.19	0.066

^a The value at immediately post-operative was compared with at final follow-up

between T2 and L5. 111 (58.4 %) pedicle screws were placed in the thoracic spine, and 84 (41.6 %) screws in the lumbar spine (Table 2). Results of the measurements described and compared can be found in Tables 3, 4 and 5.

In four patients whose follow-up time was from 76 to 97 months, having post-operative CT scans in final follow-up. Based on results of four CT examinations, comparisons were taken at the pre-operation and latest follow-up (Table 6). In these children who were hemivertebra in lumbar spine, hemivertebrectomy and short-segment fusion were performed with instrumentation of two vertebrae via bilateral pedicular screws. A total of 16 transpedicular screws were placed. The change value of anterior–posterior diameters of vertebral body were not significantly different in these patients measured by CT images or plain radiograph, but the anterior–posterior diameter of the spinal canal were significantly different, which was higher in patients measured by plain radiograph than CT scan images (Table 7).

Average length of these instrumented vertebrae after surgery varied from 18.8–24.2 mm (thoracic spine) and 21.3–27.4 mm (lumbar spine). Average length of these adjacent non-instrumented vertebrae after surgery varied from 18.6–23.2 mm (thoracic spine) and 20.6–25.7 mm (lumbar spine). As expected, the values increased from cranial to caudal. There was no significant retardation of growth in the instrumented vertebrae compared to the adjacent vertebrae. The same was valid for the average anterior and posterior height of these vertebrae. The values instrumented vertebrae: 12.5–16.0 mm (thoracic spine) and 16.5–21.1 mm (lumbar spine). The values adjacent vertebrae: 12.3–16.3 mm (thoracic spine) and 17.2–22.1 mm (lumbar spine).

There was a significant difference between the pre-operative and final follow-up values of the measurement of spinal canal and vertebral body parameters, indicating that change (growth) took place for the duration of follow-up ($P < 0.001$). There was a significant difference in distance

Table 5 (a) Only thoracic levels were selected. Levels without screws (S[–]) were compared with levels with screws (S[+ +]) for growth. (b) Only lumbar levels were selected. Levels without screws (S[–]) were compared with levels with screws (S[+ +]) for growth

Measurements (cm)	Pre-operation (average)		Last follow-up (average)		Δ (average)		P (between Δ)
	S (–)	S (+ +)	S (–)	S (+ +)	S (–)	S (+ +)	
(a)							
L (lateral)	1.88 ± 0.39	1.86 ± 0.35	2.42 ± 0.62	2.32 ± 0.54	0.54 ± 0.37	0.46 ± 0.35	0.288
H (lateral)	1.23 ± 0.29	1.25 ± 0.30	1.63 ± 0.46	1.60 ± 0.45	0.40 ± 0.30	0.35 ± 0.30	0.428
Area 1	2.41 ± 1.05	2.41 ± 1.05	4.17 ± 2.25	3.89 ± 2.16	1.76 ± 1.45	1.49 ± 1.76	0.325
CAP	1.30 ± 0.20	1.34 ± 0.24	1.53 ± 0.31	1.51 ± 0.37	0.22 ± 0.25	0.17 ± 0.27	0.294
W (P-A)	2.74 ± 0.55	2.95 ± 0.57	3.21 ± 0.84	3.23 ± 0.82	0.49 ± 0.42	0.32 ± 0.68	0.158
H (P-A)	1.20 ± 0.28	1.22 ± 0.29	1.57 ± 0.43	1.46 ± 0.45	0.38 ± 0.26	0.26 ± 0.36	0.091
Area 2	3.40 ± 1.46	3.70 ± 1.55	5.34 ± 2.80	5.02 ± 2.69	1.98 ± 1.69	1.34 ± 1.76	0.075
HIS (P-A)	0.35 ± 0.12	0.35 ± 0.12	0.41 ± 0.22	0.38 ± 0.21	0.06 ± 0.20	0.03 ± 0.18	0.451
HIS (lateral)	0.38 ± 0.16	0.40 ± 0.17	0.45 ± 0.18	0.39 ± 0.19	0.07 ± 0.18	-0.01 ± 0.17	0.016
(b)							
L (lateral)	2.13 ± 0.46	2.06 ± 0.39	2.74 ± 0.68	2.57 ± 0.52	0.61 ± 0.41	0.51 ± 0.31	0.233
H (lateral)	1.72 ± 0.42	1.65 ± 0.38	2.22 ± 0.58	2.11 ± 0.48	0.50 ± 0.39	0.46 ± 0.27	0.577
Area 1	3.82 ± 1.79	3.52 ± 1.45	6.36 ± 3.29	5.62 ± 2.47	2.55 ± 2.06	2.10 ± 1.39	0.259
CAP	1.39 ± 0.25	1.33 ± 0.23	1.57 ± 0.30	1.55 ± 0.29	0.18 ± 0.26	0.22 ± 0.23	0.481
W (P-A)	3.52 ± 0.69	3.44 ± 0.63	4.26 ± 0.95	3.89 ± 0.78	0.59 ± 0.87	0.42 ± 0.58	0.313
H (P-A)	1.49 ± 0.36	1.47 ± 0.34	2.02 ± 0.53	2.05 ± 0.58	0.48 ± 0.46	0.56 ± 0.44	0.431
Area 2	5.33 ± 1.81	5.15 ± 1.71	8.91 ± 3.93	8.35 ± 3.98	3.31 ± 3.02	3.10 ± 3.00	0.755
HIS (P-A)	0.46 ± 0.20	0.46 ± 0.19	0.66 ± 0.41	0.56 ± 0.31	0.18 ± 0.35	0.04 ± 0.29	0.070
HIS (lateral)	0.61 ± 0.22	0.54 ± 0.25	0.78 ± 0.26	0.68 ± 0.28	0.16 ± 0.24	0.12 ± 0.26	0.543
PH-L	0.80 ± 0.19	0.67	1.08 ± 0.27	1.21	0.29 ± 0.22	0.53	0.291
PH-R	0.74 ± 0.23	0.56	1.06 ± 0.28	1.21	0.29 ± 0.19	0.65	0.087

of the tips of the screws to the anterior cortex of the vertebral body between the immediately post-operative and final follow-up ($P = 0.000$). No significant difference was found between pre-operative and immediate post-operative values for the spinal canal, pedicle and vertebral body parameters, including the height and area of vertebral body, sagittal diameters of spinal canal, and the height of pedicle projection. No significant difference existed in growth rates of vertebral bodies and the sagittal diameters of spinal canal with or without screws (Tables 3, 4, 5 and 6). There was no significant difference in vertebrae with unilateral or bilateral pedicle screws (Table 8). There was no significant difference in adjacent non-instrumented vertebrae between inside and outside of fusion level (Table 9).

However, there was a significant difference in the height of intervertebral space, which is higher in outside of fusion level adjacent group than instrumented and inside of fusion level adjacent group ($P = 0.034$). The growth rates of vertebral bodies in lumbar spine were higher than in thoracic spine in both instrumented and adjacent groups. No significant difference was observed at sagittal diameters of spinal canal, parameters of pedicle projection and the distance of the tips of screws the anterior cortex of the

vertebral body in thoracic region than lumbar spine (Table 4). Either thoracic or lumbar spine group, no significant difference was found between growth rates of vertebral bodies and the sagittal diameters of spinal canal with or without screws (Table 5).

Discussion

Pedicle screw instrumentation has proved to be a reliable and safe technique over the past several decades in adults and adolescents. It allows a short fusion and the preservation of motion segments because of a rigid segmental stabilization. In spinal deformities surgery, segmental transpedicular instrumentation provides a superior correction of deformity in the coronal, sagittal, and transverse planes [13]. In pediatric scoliosis, there is no other chance to get a firm anchorage for correction and stabilization. Because the smooth bony structures do not allow a stable fixation at the posterior elements with hooks or wires. Thus, the best possibility for stable fixation at present is the insertion of transpedicular screws [22]. However, the effect of further growth of the vertebra and spinal canal after

Table 6 (a) All levels without screws (S[–]) compared with all levels with screws (S[+ +]). (b) All the levels were selected

Measurements	Pre-operation (average)		Last follow-up (average)		Δ (average)		P (between Δ)
	S (–)	S (+ +)	S (–)	S (+ +)	S (–)	S (+ +)	
(a)							
PL-L (cm)	3.51 $\pm$ 0.60	3.42 $\pm$ 0.50	4.40 $\pm$ 0.57	4.23 $\pm$ 4.40	0.89 $\pm$ 0.86	0.81 $\pm$ 0.53	0.827
PL-R (cm)	3.62 $\pm$ 0.62	3.62 $\pm$ 0.70	4.45 $\pm$ 0.69	4.19 $\pm$ 0.50	0.83 $\pm$ 0.88	0.57 $\pm$ 0.35	0.438
PW-L (cm)	0.59 $\pm$ 0.25	0.55 $\pm$ 0.18	0.81 $\pm$ 0.30	0.78 $\pm$ 0.21	0.23 $\pm$ 0.12	0.24 $\pm$ 0.22	0.9
PW-R (cm)	0.55 $\pm$ 0.16	0.47 $\pm$ 0.14	0.79 $\pm$ 0.36	0.75 $\pm$ 0.16	0.25 $\pm$ 0.21	0.28 $\pm$ 0.16	0.739
VAP (cm)	1.95 $\pm$ 0.42	1.94 $\pm$ 0.44	2.75 $\pm$ 0.36	2.46 $\pm$ 0.41	0.79 $\pm$ 0.30	0.52 $\pm$ 0.31	0.101
CAP (cm)	1.77 $\pm$ 0.30	1.80 $\pm$ 0.19	1.83 $\pm$ 0.22	1.90 $\pm$ 0.27	0.06 $\pm$ 0.31	0.11 $\pm$ 0.19	0.738
CLAT (cm)	1.96 $\pm$ 0.35	2.08 $\pm$ 0.28	2.18 $\pm$ 0.42	2.07 $\pm$ 0.23	0.21 $\pm$ 0.41	−0.01 $\pm$ 0.23	0.201
Measurements	Pre-operation (average)		Last follow-up (average)		Δ (average)		P (between Δ)
	T	L	T	L	T	L	
(b)							
PL-L (cm)	3.35 $\pm$ 0.53	3.53 $\pm$ 0.55	4.58 $\pm$ 0.55	4.16 $\pm$ 0.49	1.23 $\pm$ 1.01	0.62 $\pm$ 0.28	0.202
PL-R (cm)	3.51 $\pm$ 0.61	3.69 $\pm$ 0.67	4.52 $\pm$ 0.58	4.20 $\pm$ 0.61	1.01 $\pm$ 0.93	0.51 $\pm$ 0.36	0.143
PW-L (cm)	0.51 $\pm$ 0.09	0.6 $\pm$ 0.25	0.72 $\pm$ 0.19	0.85 $\pm$ 0.27	0.21 $\pm$ 0.19	0.25 $\pm$ 0.17	0.676
PW-R (cm)	0.42 $\pm$ 0.05	0.56 $\pm$ 0.17	0.65 $\pm$ 0.19	0.85 $\pm$ 0.30	0.23 $\pm$ 0.21	0.28 $\pm$ 0.17	0.596
VAP (cm)	1.78 $\pm$ 0.31	2.05 $\pm$ 0.45	2.65 $\pm$ 0.17	2.57 $\pm$ 0.50	0.87 $\pm$ 0.40	0.53 $\pm$ 0.20	0.091
CAP (cm)	1.69 $\pm$ 0.27	1.84 $\pm$ 0.22	1.81 $\pm$ 0.31	1.90 $\pm$ 0.19	0.13 $\pm$ 0.34	0.06 $\pm$ 0.20	0.636
CLAT (cm)	1.85 $\pm$ 0.37	2.12 $\pm$ 0.24	2.08 $\pm$ 0.46	2.15 $\pm$ 0.29	0.24 $\pm$ 0.51	0.03 $\pm$ 0.17	0.238

Thoracic levels (T) were compared with lumbar levels (L) for growth (Parameters by CT scan images)

PL indicates pedicle length, *PW* indicates pedicle width, *L* left, *R* right; *VAP* anterior–posterior diameter of vertebral body, *CAP* anterior–posterior diameter of spinal canal, *CLAT* interpedicular diameter of spinal canal

Table 7 The average value of each parameter in patients measured via X-ray and CT scan ($n = 4$, $\bar{x} \pm s$)

Measurements	X-ray	CT	<i>P</i>
VAP (pre-op)	2.12 $\pm$ 0.42	1.95 $\pm$ 0.42	0.229
VAP (follow-up)	2.80 $\pm$ 0.52	2.60 $\pm$ 0.40	0.224
Δ VAP	0.68 $\pm$ 0.29	0.66 $\pm$ 0.33	0.834
CAP (pre-op)	1.19 $\pm$ 0.11	1.78 $\pm$ 0.24	0.000
CAP (follow-up)	1.65 $\pm$ 0.20	1.87 $\pm$ 0.24	0.007
Δ CAP	0.46 $\pm$ 0.28	0.08 $\pm$ 0.25	0.000

screw insertion has been called into question. Perhaps the most important one is the fact that pedicle screws have to pass through an open and supposedly active growth plate, the NCC, to secure fixation in the pediatric spine.

A recent study by Zhang et al. [23] has been observed that the NCC starts to fuse in the lumbar segments around age 3, and proceeds to thoracic segments around the age 5 via magnetic resonance imaging. These findings have been corroborated by an anatomical study by Ginsburg and Schwend [24] performed on pediatric specimens. Zindrick et al. [25] reported the analysis of pedicle morphology of the immature thoracolumbar spine. They described that the

distance to the anterior cortex was markedly decreased in young vertebrae, although anteroposterior and interpedicular spinal canal diameters demonstrated little growth after age 3.

A study by Ruf and Harms has shown that pedicle screw fixation could be performed safely in 1- and 2-year-old children without negative effects on vertebral growth [20]. But only three patients were observed. In our study, no significant differences were found between instrumented vertebrae and the adjacent non-instrumented vertebrae, indicating that vertebral growth and spinal canal development were not retarded in these young patients. This was in line with the study of Olgun et al. [22]. In their study, 15 patients less than 5 years were consisted undergoing pedicle screw instrumentation. They investigated the effect of pedicle screws on vertebral growth by measuring growth parameters on CT axial images.

In our study, no negative effect of the pedicle screw instrumentation could be determined on vertebral bodies' growth on plain radiographs. No spinal stenosis existed in an average of 7 years after instrumentation on CT axial images. There was no significant difference in vertebrae with unilateral or bilateral pedicle screws. It suggested that the effect of the contralateral screw on the non-screw pedicle could be

Table 8 Only the levels with screws were selected

Measurements (cm)	Pre-operation (average)		Last follow-up (average)		Δ (average)		<i>P</i> (between Δ)
	S (+)	S (+ +)	S (+)	S (+ +)	S (+)	S (+ +)	
L (lateral)	1.79 $\pm$ 0.34	1.83 $\pm$ 0.30	2.25 $\pm$ 0.44	2.28 $\pm$ 0.40	0.46 $\pm$ 0.32	0.46 $\pm$ 0.31	0.610
H (lateral)	1.32 $\pm$ 0.35	1.26 $\pm$ 0.32	1.69 $\pm$ 0.45	1.68 $\pm$ 0.43	0.37 $\pm$ 0.33	0.41 $\pm$ 0.27	0.647
Area 1	2.45 $\pm$ 1.06	2.38 $\pm$ 0.95	3.94 $\pm$ 1.88	3.93 $\pm$ 1.53	1.49 $\pm$ 1.22	1.54 $\pm$ 0.88	0.870
TCD ^a	0.55 $\pm$ 0.21	0.47 $\pm$ 0.18	0.90 $\pm$ 0.37	0.85 $\pm$ 0.43	0.35 $\pm$ 0.33	0.38 $\pm$ 0.31	0.769
CAP	1.34 $\pm$ 0.16	1.34 $\pm$ 0.15	1.42 $\pm$ 0.44	1.55 $\pm$ 0.18	0.05 $\pm$ 0.45	0.15 $\pm$ 0.21	0.328
W (P-A)	3.19 $\pm$ 0.63	3.10 $\pm$ 0.54	3.39 $\pm$ 0.58	3.40 $\pm$ 0.55	0.19 $\pm$ 0.38	0.30 $\pm$ 0.37	0.373
H (P-A)	1.16 $\pm$ 0.23	1.23 $\pm$ 0.26	1.42 $\pm$ 0.49	1.55 $\pm$ 0.36	0.27 $\pm$ 0.35	0.32 $\pm$ 0.31	0.641
Area 2	3.78 $\pm$ 1.46	3.91 $\pm$ 1.37	5.05 $\pm$ 2.77	5.41 $\pm$ 2.04	1.26 $\pm$ 1.53	1.49 $\pm$ 1.53	0.655
HIS (P-A)	0.37 $\pm$ 0.10	0.33 $\pm$ 0.11	0.29 $\pm$ 0.17	0.38 $\pm$ 0.19	0.07 $\pm$ 0.19	0.05 $\pm$ 0.19	0.062
HIS (lateral)	0.35 $\pm$ 0.11	0.39 $\pm$ 0.16	0.41 $\pm$ 0.22	0.37 $\pm$ 0.15	0.05 $\pm$ 0.25	0.01 $\pm$ 0.15	0.270

Levels with unilateral screws (S [+]) were compared with levels with bilateral screws (S [+ +]) for growth

^a The value at immediately post-operative was compared with at final follow-up

Table 9 The average change of each parameter in three groups (last follow-up measurement minus the pre-operative measurement) ($n = 6$, $\bar{x} \pm s$)

Measurements (cm)	Instrumented group	Outside of fusion level adjacent group	Inside of fusion level adjacent group	<i>P</i>
L (lateral)	0.48 $\pm$ 0.26	0.59 $\pm$ 0.37	0.49 $\pm$ 0.35	0.59
H (lateral)	0.51 $\pm$ 0.27	0.69 $\pm$ 0.53	0.25 $\pm$ 0.12	0.06
Area 1	2.04 $\pm$ 1.07	2.92 $\pm$ 2.37	1.29 $\pm$ 0.40	0.08
CAP	0.29 $\pm$ 0.23	0.33 $\pm$ 0.29	0.31 $\pm$ 0.28	0.88
W (P-A)	0.29 $\pm$ 0.56	0.66 $\pm$ 0.63	0.48 $\pm$ 0.35	0.24
H (P-A)	0.45 $\pm$ 0.48	0.56 $\pm$ 0.43	0.34 $\pm$ 0.31	0.63
Area 2	1.89 $\pm$ 2.04	3.45 $\pm$ 3.19	2.03 $\pm$ 1.77	0.24
HIS (P-A)	0.05 $\pm$ 0.22	0.13 $\pm$ 0.27	0.08 $\pm$ 0.27	0.32
HIS (lateral)	0.04 $\pm$ 0.26	0.22 $\pm$ 0.22	0.16 $\pm$ 0.22	0.02

not obvious. There was no significant difference in growth rates of vertebral bodies and sagittal diameters of spinal canal in adjacent non-instrumented vertebrae between inside and outside of fusion level. But the height of intervertebral space is higher in outside of fusion level adjacent group than instrumented and inside of fusion level adjacent group. The explanation might be that the growth of intervertebral disc was retarded after instrument and fusion.

In our study, whether there was at the thoracic segment or lumbar segment, pedicle screws did not cause a retardation effect on the development of vertebral bodies and the spinal canal. Considering that the NCC in lumbar regions closes slightly earlier than thoracic levels, we have compared the growth rates of thoracic and lumbar levels. The results showed the lumbar spine was higher for growth rates than in thoracic spine in either instrumented or adjacent groups, but growth retardation was not the case.

The limitation of this study was the usage of plain radiographs instead of computed tomography (CT) or visual examination for the evaluation of the parameters of vertebral bodies and spinal canal. Though only four patients who had postoperative CT imaging were in inclusion. The fact observed was that no spinal stenosis existed in an average of 7 years after instrumentation. To determine the reliability of plain radiograph, the comparison was performed on parameters measured via CT scan images and X-ray. The length and the change value of anterior–posterior vertebral body were not significantly different in patients via CT images or plain radiograph, but the anterior–posterior diameter and change of the spinal canal were higher in these patients via plain radiograph than CT scan images. An explanation might be that the overlap shadow in plain radiograph brought in this discrepancy. There is no doubt that CT is more accurate than X-ray. But in clinical, we have attempted to decrease patients' exposure to radiation. Thus, we had to contend with less clear plain radiographs. The artifacts left by metal implants in the patients' instrumented levels might interfere with measurement and affect results.

The other drawback was that although all patients have been followed-up for at least 24 months, part of children' growth is not yet complete. It can be speculated that the evaluation of the effect of pedicle screws on growth would be better performed after the completion of skeletal maturation. However, prior studies have suggested NCC is mostly closed by the age of 7, and the spinal canal reaches 86 % of its adult proportions at the age of 5 [25–27]. It can be appreciated that the at least 2-year follow-up study comprises some of the most critical aspects of spinal canal growth. Thus, in spite of the fact that evaluation of the growth of the subjects is incomplete, it does not affect the reliability of the results.

In conclusion, pedicle screw instrumentation does not seem to cause a retardation effect on the development of vertebral bodies and the spinal canal in children who require instrumentation at an early age. Pedicle screw instrumentation is a reliable procedure to achieve a stable fixation. Of course, further follow-up will be necessary, especially during growth spurt.

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Conflict of interest The authors declare that they have no conflict of interests related to this work.

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