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ORIGINAL ARTICLE

Segmental vs non-segmental thoracic pedicle screws constructs in adolescent idiopathic scoliosis: is there any implant alloy effect?

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Abstract
Purpose The aim of this study is to understand how many anchor sites are necessary to obtain maximum posterior correction of idiopathic scoliotic curve and if the alloy of instrumentation, stainless steel or titanium, may have a role in the percent of scoliosis correction.
Methods We reviewed 143 consecutive patients, affected by AIS (Lenke 1–2), who underwent a posterior spinal fusion with pedicle screw-only instrumentation between 2002 and 2005. According to the implant density and alloy used we divided the cohort in four groups.
Results All 143 patients were reviewed at an average follow-up of 7, 2 years, the overall final main thoracic curve correction averaged 61.4%, whereas the implant density within the major curve averaged 71%. A significant correlation was observed between final% MT correction and preoperative MT flexibility and implant density.
Conclusions When stainless steel instrumentation is used non-segmental pedicle screw constructs seem to be equally effective as segmental instrumentations in obtaining satisfactory results in patients with main thoracic AIS. When the implant alloy used is titanium one, an implant density of ≥60% should be guaranteed to achieve similar results.

Keywords Adolescent idiopathic scoliosis · Posterior instrumented fusion only · Implant density · Titanium vs stainless steel

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Introduction

Since its introduction by Suk [1], the use of thoracic pedicle screw has increasingly become widespread in the treatment of the adolescent idiopathic scoliosis (AIS) and had led to a significant improvement in deformity correction [2–6].

Recently, the relevance of adopting a higher pedicle screw density in scoliosis surgery is object of discussion. Clements et al. [7] introduced the concept of "implant density", defined as the number of fixation anchors placed for available anchor sites, so it is the % of pedicle used for the implants: they concluded that there was a significant correlation between pedicle screw density and the percentage of curve correction. Quan et al. [8] instead concluded that bilateral segmental pedicle screw fixation do not improve curve correction compared with unilateral and segmental fixation. Similarly, Gebhart et al. [9] found no correlation between increasing pedicle screw density and main thoracic curve correction. However, there is agreement concerning the effect of implant density on sagittal profile: sagittal contour of thoracic spine resulted in a less kyphosis than higher the implant density was [7, 8].

The aim of this study is to understand how the percentage of pedicle screws used for the instrumentation can allow the better correction and its effect on sagittal profile. Another aspect considered in this series is the influence of the instrumentation alloy (titanium vs stainless steel) and its possible correlation with overall correction rate.

Materials and methods

Patient evaluation

A retrospective review, based on a database search, was performed to identify all AIS patients who had undergone posterior spinal fusion with pedicle screw-only instrumentation between 2002 and 2007 at the reference center. The inclusion criteria were: (1) diagnosis of adolescent idiopathic scoliosis; (2) main thoracic or thoracolumbar curve (Lenke type 1, 2); (3) posterior fusion using pedicle screw-only construct; (4) a minimum clinical and radiographic follow-up of 5 years.

An independent spine surgeon reviewed all the medical records and X-rays of the patients considered. Inpatient and outpatient charts were used for collecting demographic data, peri-operative treatment, and annotation of any medical and surgical-related complications, including revision surgeries. Radiographic evaluation included standing posterior-anterior and lateral films on long-cassettes (90 × 30 cm), before and after surgery and at the latest follow-up. The Lenke classification of AIS was used to describe curve patterns. Cobb measurements of the major thoracic (MT) curves were obtained, and the lateral films were evaluated for thoracic kyphosis (T5–T12). MRI of the spine, including cervical, thoracic and lumbar segments, was performed preoperatively to exclude congenital intramedullary anomalies.

A total of 143 consecutive patients (one single institution, three different surgeons) fulfilled our inclusion criteria, who had undergone a posterior spinal fusion with pedicle screw-only instrumentation. According to the implant density (number of fixation anchors placed per available anchors sites; segmental $\geq$60%, non-segmental <40%) and implant alloy used (Ti: titanium vs SS: stainless steel) we divided the aforementioned cohort in four groups, titanium segmental (48 patients) and non-segmental (34), stainless steel segmental (35) and non-segmental (26).

Operative procedures

Intraoperative monitoring of spinal cord function was provided in all patients of each group by recording Somatosensory evoked potentials (SEPs) and Transcranial Electric Stimulation-Motor evoked potentials (TES-MEPs). A neurophysiological change was defined relevant when it consisted of a persistent unilateral or bilateral reduction in amplitude $\geq$50% for SEPs and $\geq$65% for TES-MEPs compared with baseline.

The same operating table was used in all patients. All cases underwent posterior instrumented fusion after a meticulous exposure of the posterior elements of the spine to the tips of the transverse processes bilaterally. For thoracic screw placement we used the free-hand procedure [10], and sometimes for apical concave screws the spatula technique [11, 12] that allowed for inspection with a spatula inside the canal of the borders of the pedicle, after excision of spinous process and ligamentum flavum. A radical posterior release was performed in every patient at each level to be fused, obtaining a Ponte osteotomy at 3–4 levels for apical vertebrae. In all cases we used monoaxial reduction screws at each level; polyaxial reduction screws were occasionally used in more severe scoliosis in peri-apical sites to reduce the difficulties of rod capture. Concerning instrumentation, a stainless steel one was used for a group of patients and a titanium one for the others. Arthrodesis was carried out using banked bone (obtained from femoral epiphyses) and autologous chips obtained from resected spinous processes.

Instrumentation consisted of all pedicle screws. The titanium group cases were divided into 48 segmental constructs and 34 non-segmental one; on the other hand the stainless steel group, 61 cases, into 35 segmental construct and 26 non-segmental.

In all cases the deformity correction was carried out using a combination of different corrective techniques, including rod cantilevering, translation and concave rod rotation maneuvers. The operation time averaged a mean of 320 min (range 230–350 min). Mean intraoperative bleeding was 860 ml (range 600–1200 ml, with a mean estimated blood loss of 14.4, and 12.7 cc/kg, respectively). No postoperative brace or a cast was used in any of the patients.

Questionnaires

Six self-reported, patient-based outcome tools, the Italian version of the SRS-30 were obtained by all patients during the last follow-up visit based on the self-image and satisfaction. Statistical analysis was performed using the *t* test (paired and unpaired), the Wilcoxon test for non-parametric paired analysis, and the Mann–Whitney test for non-parametric unpaired analysis. Results are expressed as the mean (range), with a p value of <0.05 considered as being statistically significant.

Results

The entire series of 143 cases were reviewed at an average follow-up of 7.2 years (range 5–10 years). There were no statistical differences between the four group, in terms of age, Risser's sign, curve patterns according to Lenke's classification, Cobb preoperative main thoracic (MT) curve magnitude and flexibility on supine side bending, offset measurements on the coronal plane and sagittal preoperative contour (Table 1).

At follow-up, the overall final main thoracic curve correction averaged 61.4% (20–89), whereas the implant density within the major curve averaged 71% (15–100). A significant correlation was observed between final % MT correction and Preop. Main Thoracic flexibility ($r = 0.46$, $p < 0.001$) and implant density ($r = 0.41$, $p < 0.002$) (Table 2).

The titanium group ($n = 82$ patients) was divided into 48 segmental and 34 non-segmental constructs, based on the percentage of pedicle available for the fusion used, if more or less then 60%. The Ti-segmental had a mean age at surgery of 12.1 years (11–16) and a mean Risser's sign of 1.4 (0–3) (Table 1). The preoperative MT Cobb was of 66° (52–80), which presented on spine bending test a flexibility of 42% (22–56), and achieved a follow-up correction of 68.3% (39–72) (Tables 3, 4).

The Ti-non-segmental group had a mean age at surgery of 13.4 years (12–14), and a mean Risser's sign of 2.4 (0–4). The preoperative MT Cobb was of 63° (50–75), which presented on spine bending test a flexibility of 40% (15–53), and its follow-up correction was 52% (15–70).

The stainless steel group ($n = 61$ patients) was divided into the segmental group composed by 35 patients and the non-segmental group with 26 cases; the division was based on the percentage of pedicle available for the fusion used, more or less then 60%. The SS-segmental group had a mean age at surgery of 12.8 years (11–14) and a mean Risser's sign of 2.5 (0–4). This group showed a mean preoperative Cobb of 69° (59–85), with a flexibility on bending test of 39% (22–49), see in Table 1. The overall correction was 75% (45–100) for the coronal plane (Tables 3, 4).

The SS-non-segmental group had a mean age at surgery of 14.2 years (12–14) and a mean Risser's sign of 1.8 (0–3). The SS-NS group showed a preoperative Cobb of 62° (53–78), with flexibility on bending test of 41% (23–58) as in Table 1. The final correction was 62.3% (35–71), as in Tables 3 and 4.

In conclusion, when the four distinct groups were compared, the Ti-NS group showed a statistically

Table 1 The entire series of 143 patients: the four groups (titanium segmental and non-segmental, stainless steel segmental and non-segmental) were similar for preoperative average age, Risser's sign, Lenke's type distribution, main thoracic curve and thoracic kyphosis Cobb angle, preoperative main thoracic flexibility on supine side-bending test

	Titanium-S $N = 48$	Titanium-NS $N = 34$	SS-S $N = 35$	SS-NS $N = 26$
Age	12.1 (11–16)	13.4 (12–14)	12.8 (11–14)	14.2 (12–14)
Risser's sign	1.4 (0–3)	2.4 (0–4)	2.5 (0–4)	1.8 (0–3)
Lenke's type distribution	30 (1); 18 (2)	22 (1); 12 (2)	23 (1); 12 (2)	16 (1); 10 (2)
MT scoliosis°	66 (52–80)	63 (50–75)	69 (59–85)	62 (53–78)
MT flexibility	42% (22–56)	40% (15–53)	39% (22–49)	41% (23–58)
T5–T12 kyphosis°	35.3 (10–41)	30.2 (15–39)	32.7 (18–37)	28.7 (12–35)

S segmental, *-NS* non-segmental, *SS* stainless steel, *MT* main thoracic

Table 2 Results: at follow-up, the overall final main thoracic curve correction averaged 61.4%, whereas the implant density within the major curve averaged 71%

	Entire series	p	r
Final MT correction	61.4 ± 18.6%	<0.001	–
Implant density	71 ± 13.7%	–	–
Final MT correction vs flexibility	–	<0.001	0.46
Final MT correction vs implant density	–	<0.002	0.41

A significant correlation was observed between final % MT correction and Preop. Main Thoracic flexibility ($r = 0.46$, $p < 0.001$) and implant density ($r = 0.41$, $p < 0.002$)

MT main thoracic

Table 3 Results: when the four distinct groups were compared, the titanium non-segmental group (Ti-NS) showed a statistically significant inferior percent MT curve correction

	Ti-S	Ti-NS	SS-S	SS-NS
Final MT correction	68.3% (39–72)	52% (15–70)	75% (45–100)	62.3% (35–71)

MT main thoracic, *Ti-S* titanium segmental, *Ti-NS* titanium non-segmental, *SS-S* stainless steel segmental, *SS-NS* stainless steel segmental

Table 4 Results: there were no statistically significant differences for scoliosis curve correction between stainless steel segmental vs titanium segmental vs stainless steel non-segmental (SS-S vs Ti-S vs SS-NS) cases

	p	*r*
SS-S vs Ti-S	>0.05	0.002
SS-S vs SS-NS	>0.05	0.13
Ti-S vs SS-NS	>0.01	0.07

S segmental, *NS* non-segmental, *SS* stainless steel, *MT* main thoracic

significant inferior percent MT correction, i.e., 52% with a range from 15 to 70% (Table 3), and no statistically significant differences between SS-S vs Ti-S vs SS-NS was seen (Table 4).

Concerning the coronal balance radiographic measurements, we observed that the thoracic kyphosis, T5–T12 angle (Table 1) was quite similar in each group before surgery, Ti-S was 35.3° (10–41), Ti-NS 30.2° (15–39), SS-S was 32.7° (18–37) and SS-NS was 28.7° (12–35). At follow-up control the absolute final thoracic kyphosis resulted similar ($p > 0.05$), with groups showing an equally statistical significant amelioration ($p < 0.001$) of the sagittal contour (Table 5), in titanium group goes to 37.4° ± 17.2° for the segmental group and to 33.4° ± 15.1° for the non-segmental one with a final correction of 42.2 ± 9.3 and 43.4 ± 12.9%, respectively. The stainless steel patients follow-up was 35.4° ± 12.2° for the segmental group and 32.4° ± 15.1° for the non-segmental, with an overall correction of kyphosis of 46.4 ± 12.9 and 47.2 ± 9.3%. At follow-up, no hypo-kyphogenic effect was observed in this cohort of 143 AIS patients. In conclusion, we found a significant correlation between absolute correction of thoracic kyphosis and implant density was observed in all groups ($r = 0.39$, $p < 0.01$) (Table 6), while the Ti-NS group showed the inferior correlation ($r = 0.36$, $p < 0.01$) between groups.

Questionnaires

Questionnaires scores were available in all patients, at the last follow-up. Preoperative to postoperative comparison of SRS scores could not be performed since the majority of patients. In all, groups had undergone surgery before an Italian version of the SRS-30 questionnaire was available. At the latest follow-up, SRS-30 findings were similar between the four groups, with mean scores shown in Fig. 1.

Discussion

In recent years, there was an increasing use of the “pedicle screw-only construct” in the posterior correction of AIS, dramatically changing how surgeons approach and treat spinal deformities [13]. Several previous reports have demonstrated superiority of pedicle screws in correction of scoliosis in terms of mean absolute degrees and percent of curve correction in comparison to posterior hook and wire or hybrid constructs [5, 6, 14].

It is still object of discussion if a larger use of screws can allow a better scoliosis correction [7–9, 15, 16]. Recently different pedicle screws strategies have been compared: Wang et al. [16] considered three different pedicle screw strategies (interval, skipped and key-vertebral pedicle screw procedures) obtaining similar results. Similarly, others studies [8, 9, 15] concluded that there were no significant differences in radiographic results or clinical outcomes. On the contrary, in our series, a significant correlation was observed between final % MT correction and preoperative main thoracic flexibility ($r = 0.46$, $p < 0.001$) and implant density ($r = 0.41$,

Table 5 Results: absolute final thoracic kyphosis resulted similar ($p > 0.05$), with groups showing an equally statistical significant amelioration ($p < 0.001$) of the sagittal contour; at follow-up, no hypo-kyphogenic effect was observed in this cohort of 143 AIS patients3

	Ti-S	Ti-NS	SS-S	SS-NS
Final thoracic kyphosis	37.4° ± 17.2°	33.4° ± 15.1°	35.4° ± 12.2°	32.4° ± 15.1°
Overall kyphosis correction	42.2 ± 9.3%	43.4 ± 12.9%	46.4 ± 12.9%	47.2 ± 9.3%

-S segmental, *-NS* non-segmental, *SS* stainless steel, *MT* main thoracic

Table 6 Results: a significant correlation between absolute correction of thoracic kyphosis (final-preop) and implant density ($r = 0.39$, $p < 0.01$) was observed in all groups: the Ti-NS group showed the inferior correlation ($r = 0.36$, $p < 0.01$) between groups

	Overall		Ti-S		Ti-NS		SS-S		SS-NS	
	p	*r*	*p*	*r*	*p*	*r*	*p*	*r*	*p*	*r*
Kyphosis correction (final-preop) vs implant density	0.001	0.39	0.02	0.43	0.01	0.36	0.03	0.48	0.05	0.05

Ti-S titanium segmental, *Ti-NS* titanium non-segmental, *SS-S* stainless steel segmental, *SS-NS* stainless steel non-segmental

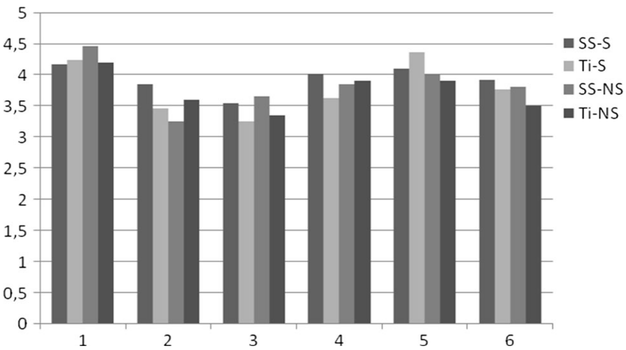


Fig. 1 The SRS-30 assessment showed an improvement in both self-image and satisfaction, without significant differences between groups. *Ti-S* Titanium segmental, *Ti-NS* titanium non-segmental, *SS-S* stainless steel segmental, *SS-NS* stainless steel non-segmental

$p < 0.002$) (Table 2). In agreement with Clements et al. study [7] there was a significant correlation between implant density and % scoliosis correction: using a titanium instrumentation final main thoracic curve correction resulted higher in segmental cases (68.3 vs 52%) (Fig. 2).

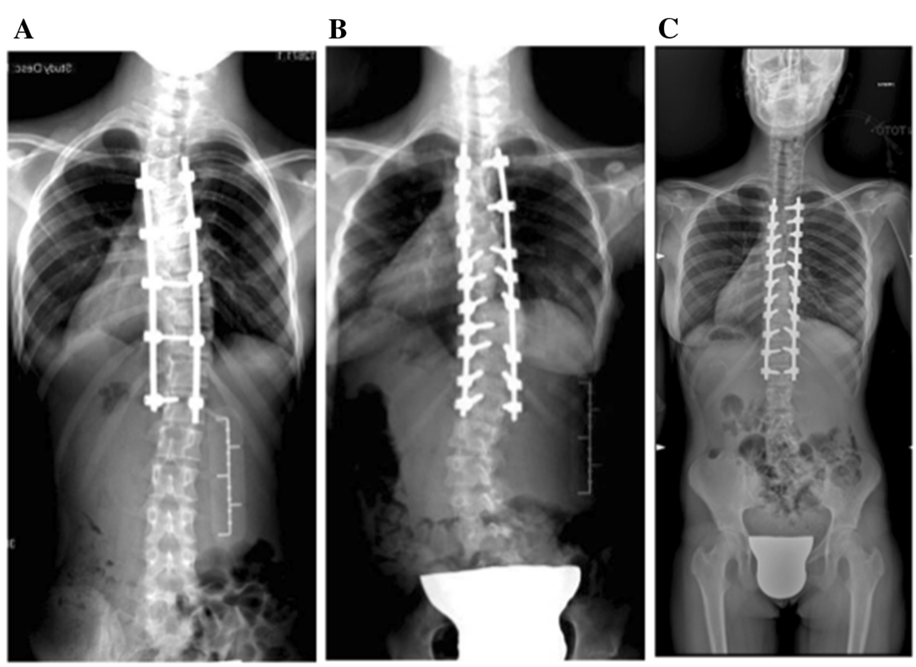
The optimal rod stiffness to correct scoliotic curves has yet to be determined. In our series, considering the instrumentation alloy (titanium vs stainless steel) the curve correction resulted higher in stainless steel cases with higher density of screws (75%). When the four distinct groups were compared, the titanium non-segmental group (Ti-NS) showed a statistically significant inferior percent MT curve correction (52%) compared with titanium segmental (68.3%), stainless steel non-segmental (62.3%) (Table 3).

Recently, an improved scoliosis correction has been obtained using rods of cobalt-chromium (CoCr). Lamerain et al. [17] evaluated the results using stainless steel and cobalt-chromium rods materials for treatment of AIS: CoCr rods have the ability to produce higher correction rates in frontal plane compared to SS rods. Moreover, CoCr rods present the advantage of being compatible with magnetic resonance imaging.

Concerning the sagittal profile, after posterior AIS correction using screw-only construct, Clements et al. [7] adds that sagittal contour in the thoracic spine became less kyphotic than the higher the implant density. This is confirmed also by Quan et al. [8], in fact they concluded that pedicle screw constructs provided excellent coronal correction of thoracic idiopathic scoliosis, however, this was at the expense of sagittal contour. In our series, the thoracic kyphosis, T5–T12 angle (Table 1) was quite similar in each group before surgery. At follow-up control the absolute final thoracic kyphosis resulted similar ($p > 0.05$), with groups showing an equally statistical significant amelioration ($p < 0.001$) of the sagittal contour (Table 5). Moreover, a significant correlation between absolute correction of thoracic kyphosis and implant density was observed in all groups ($r = 0.39$, $p < 0.01$) (Table 6).

Another point of discussion is related to clinical outcomes obtained by different instrumentation constructs. In an era of focus on cost effectiveness in medicine, the increased cost of a higher screw density must be shown to correlate with measurable improvements in outcome [9]. Regardless of the implant density or the alloy used, mid-term self-assessment (by means of SRS-30) was similar in our cases showing a postoperative improvement in both self-image and satisfaction. In our results, SRS-30 findings were similar between the four groups (titanium or stainless

Fig. 2 Definition of non-segmental and segmental construct according to the implant density: nonsegmental when the implant density is inferior to 60% (**a**) and segmental when the implant density exceed 60% (**b**, **c**)



steel, segmental or non-segmental) without significant differences between groups: it means that a more expensive construct for scoliosis correction is not always correlated with an increased satisfaction for patients. Similar clinical outcomes after different pedicle screw density are confirmed in recent studies [15, 16].

Conclusions

According to present series results, when stainless steel instrumentation is used non-segmental pedicle screw constructs seem to be equally effective as segmental instrumentations in obtaining satisfactory results in patients with main thoracic AIS. When the implant alloy used is titanium one, an implant density of $\geq$60% should be guaranteed so as to achieve similar results.

Compliance with ethical standards

Conflict of interest All authors disclose any financial and personal relationships with other people or organization that could inappropiately influence their work.

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