



Hybrid instrumentation for correction of adolescent idiopathic scoliosis

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New technology and instrumentation techniques are continually entering the spine field, leaving the scoliosis surgeon with a wide variety of options for the treatment of adolescent idiopathic scoliosis. All-screw constructs are currently the most popular. However, they remain controversial because of possible complications, and also because they have been associated with a decrease in thoracic kyphosis, not observed with hybrid instrumentation. The aim of the present study was to evaluate a hybrid construct : hooks and wires proximally, but pedicle screws distally. Forty-three patients with a minimum 2-year follow-up were included. The mean preoperative Cobb angle of the major curve was $60.85^\circ \pm 21^\circ$. At the final evaluation it was reduced to $28.44^\circ \pm 11.9^\circ$ (mean correction 53.3%, $p < 0.0001$). The mean translation of the apical vertebra was corrected from -19.13 ± 49 mm to -9.42 ± 28.9 mm. The average thoracic kyphosis improved from $24^\circ \pm 14.3^\circ$ preoperatively to $30.7^\circ \pm 7.1^\circ$, representing a mean correction of 28%. Kyphosis at the T10-L2 level was within normal values in all patients at the final evaluation. Complications included one superficial infection, one implant removal due to late onset wound infection, and 2 revisions to extend the fusion more distally. In other words, operative treatment with hybrid instrumentation yielded satisfactory results, with less risk of neurological damage. An excellent outcome in all planes could be safely achieved and maintained for a minimum of 2 years. **Conclusion : why use an expensive all-screw construct, knowing that a hybrid construct is kyphosis sparing, cheaper, safer and more resistant to pull-out ?**

Keywords : adolescent idiopathic scoliosis ; surgical treatment ; all-screw construct ; hybrid construct ; curve correction.

INTRODUCTION

Adolescent idiopathic scoliosis is a complex 3-dimensional musculoskeletal disorder characterized by lateral spine curvature in the coronal plane, thoracic hypo-kyphosis in the sagittal plane and vertebral rotation in the transverse plane. Epidemiologic studies show that 2 to 3% of the adolescent population is affected. However, less than 10% of these patients require treatment (19). Over the past years, surgery has mainly focused on correcting the coronal curve, but nowadays the aims of posterior fusion and instrumentation are to achieve a stable, well-balanced spine in the coronal as well as in the sagittal planes, prevent curve progression and also achieve solid fusion, whilst keeping the fusion as short as possible (30).

Without doubt, over the last few years the use of pedicle screws has gained in popularity, due to its perceived superior ability of curve correction in the coronal plane (25). However, clinical concern has

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focused on the safe application of these screws (7), especially at the thoracic level, mainly because the morphology of scoliotic thoracic vertebrae differs from that of the vertebrae in normal spines. Furthermore, although pedicle screws are highly effective, they have been associated with a potential decrease of the thoracic kyphosis (29). In sharp contrast, hybrid instrumentation is safer at the thoracic level, and leads to a satisfactory correction, not only in the coronal plane, but also in the sagittal plane (20). The purpose of this retrospective study was to report the outcome of surgical correction achieved by hybrid instrumentation in a single institution.

MATERIALS AND METHODS

Forty-three consecutive patients (14 males and 29 females), in whom a hybrid construct was used between 2000 and 2008, were retrospectively reviewed. The mean age of the patients at the time of surgery was 14.4 years (range : 10.2-18.1 years), and the minimum follow-up was 2 years (mean, 3.4 years ; range : 2-9 years). The curves were evaluated according to the Lenke *et al* (16) classification system. There were no patients who had undergone previous spine surgery.

Standard 36-inch posteroanterior and lateral radiographs of the entire spine, taken with the patient standing, were used to measure coronal and sagittal parameters. The curves were measured using the Cobb technique. Radiographic analysis of the *coronal plane* included the major curve Cobb angle, translation of the apical vertebra as the distance in millimeters from the central sacral line to the mid-point of the apical body, and coronal balance as the distance between the C7 plumb-line and the center sacral vertical line. Spinal imbalance was recorded when the horizontal distance of the C7 spinous process from the center sacral line exceeded 2 cm. The minus (-) sign was used to express the translation or imbalance to the right and the plus (+) sign to the left. *Sagittal plane* parameters included : thoracic kyphosis measured from the superior endplate of T3 to the inferior endplate of the T12, thoracolumbar junctional kyphosis measured from T10 to L2, and lumbar lordosis measured from the upper endplate of L1 to the upper endplate of S1. Positive values were used to indicate kyphosis and negative values to indicate lordosis. Patients were considered to have postoperative distal junctional kyphosis when the T10-L2 angle was greater than 10°. Normal

values for thoracic kyphosis were 10°- 40°. Overall, sagittal spinal balance was assessed as the distance between the C7 plumb-line and the anterior corner of the sacrum on an upright long lateral radiograph of the spine. Positive values indicated that the plumb-line was in front of the sacrum whereas negative values meant the opposite. Patients in whom C7 was within +2 cm or -2 cm from the anterior sacral corner were considered balanced in the sagittal plane.

The percentage correction was calculated using the following formula as described by Mielke *et al* (23) : % correction = [(preoperative value – follow-up value) / preoperative value] × 100. Measurements were performed before surgery, as well as immediately after surgery, one year postoperatively and at the last follow-up. All measurements were performed by a single observer.

Radiographic analysis also included the rigidity of the curves, based on preoperative left and right bending radiographs compared with the standing posteroanterior radiograph. Prior to all surgical procedures, intramedullary abnormalities or other causes of scoliosis were ruled out by MRI.

In addition, all patients had pulmonary function tests before surgery.

All patients underwent posterior spinal arthrodesis by means of hybrid instrumentation (hooks and wires proximally, pedicle screws distally) (Fig. 1) after a standard posterior midline incision. Thorough exposure of the posterior elements of the thoracic spine was made to the tip of the transverse processes bilaterally. The number of vertebral segments to be fused was based on the curve type. Laminar, transverse process and pedicle hooks as well as wires were placed proximally while pedicle screws were inserted into the distal vertebrae. The upmost hooks were always placed in a claw pattern. The pedicle screws were placed using a free hand technique. The correction was achieved using various techniques : derotation of the rod, cantilever reduction, translation and in situ rod bending. Finally, apical compression in the convexity and distraction in the concavity were carried out, in order to achieve additional correction in both planes, on the one hand, and on the other hand to restore the coronal balance. Arthrodesis included decorication of the laminae, cleaning of the facet joints and application of autografts and allografts. From 2002 on, the patients were constantly monitored via somatosensory and motor-evoked potentials. Autotransfusion was used. All patients were allowed to return to school within the first month postoperatively. They were also given an exercise protocol for a six month period till they returned to their preoperative daily activities.

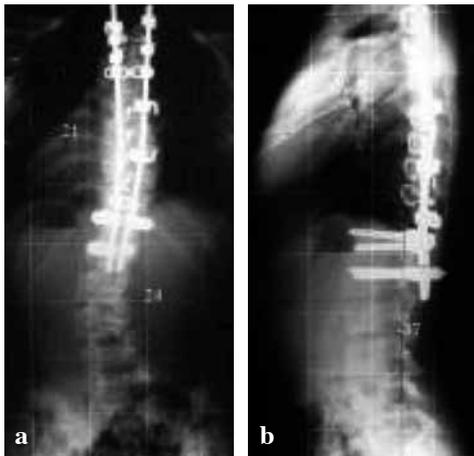


Fig. 1a,b. — AP and lateral plain radiographs. Hybrid construct : hooks and wires proximally, pedicle screws distally. A 58% correction of the thoracic curve was obtained. The preoperative thoracic lordosis was corrected to an acceptable kyphosis, while the lordosis of the lumbar area was corrected by 12%.

Statistical analysis

The SPSS was used (ver. 13.0K, SPSS Inc., Chicago, IL). The Repeated Measures ANOVA was applied, and all measurements were compared with a paired t-test, using Bonferroni's correction, in order to correct the probability at which the test was accepted. A p value < 0.05 was considered to be significant.

RESULTS

The most frequent curve type was Lenke type 1 (32 patients, 74.41%), followed by Lenke type 3 (4 patients, 9.3%). There were also 2 patients with Lenke type 2 (4.65%), one with type 4 (2.32%), 3 with type 5 (6.97%) and one with type 6 (2.32%). As to kyphosis, 29 patients were normokyphotic (T3-T12, 10° to 40°), 8 hyperkyphotic (T3-T12, > 40°) and 6 hypokyphotic (T3-T12, < 10°).

The average number of levels fused was 14 (range : 6-15). The distal fusion level was T11 in 2 patients, T12 in 2, L1 in 9, L2 in 11, L3 in 8, L4 in 4 and L5 in 6. The average operating time was 270 ± 40 minutes and the mean intraoperative blood loss 930 ± 103 ml.

Coronal plane : the main coronal curve was 60.85° ± 21.1° (Table I), with a mean flexibility of 47.5%. The immediate postoperative Cobb angle

was 24.21° ± 12.3° (Fig. 1a). This reduction of the Cobb angle averaged 60.2% and was statistically significant (p < 0.0001). The mean Cobb angle was 28.25° ± 10.5° at the 1-year follow-up (p < 0.0001), and 28.44° ± 11.9° at the final follow-up, still demonstrating a 53.3% correction (p < 0.0001). There was a loss of correction of 4.23° ± 0.4° between the early postoperative correction and the final follow-up. The mean coronal balance was -0.09 ± 19.9 mm preoperatively (range, -45 mm to 40 mm) with a postoperative mean value of 4.60 ± 15.6 mm (range, -30 mm to +33 mm) and of 4.44 ± 12.9 mm at final follow-up : all these corrections were not significant. The mean translation of the apical vertebra was corrected from -19.13 ± 49.9 mm (range, -140 to +81) preoperatively, to -5.07 ± 26 mm at the immediate postoperative evaluation (73% improvement, p < 0.04). At the last follow-up the mean translation of the apical vertebrae was -9.42 ± 28.9 mm (p < 0.021).

Sagittal plane : the mean preoperative thoracic kyphosis (Table II) was 24° ± 13° and it was corrected to 33.4° ± 7.5° immediately after surgery (Fig. 1b). This corresponded to a mean kyphosis correction of 39.2%. At 1-year follow-up, the mean kyphosis was 31.5° ± 7.2°. The final value was 30.7° ± 7.1°. None of these corrections was significant, but the kyphosis was improved. Changes in lumbar lordosis and sagittal balance were not significant. As to the thoracolumbar junction, patients were slightly kyphotic at the T10-L2 level with a mean of 4.86° ± 12.32°, which improved to -2.6° ± 7.51° postoperatively and remained within the same range at the last follow-up (-2.50° ± 6.12°). None of the patients developed proximal junction kyphosis during the follow-up.

The present study demonstrates that hybrid instrumentation satisfactorily corrects the curvature and that the correction is maintained in the long term.

COMPLICATIONS

No intraoperative complications were seen. Postoperative complications were noted in 4 patients (9.3%). Two of these had an infection, respectively after 10 days and after 2.5 years. Implant removal was necessary in the second case. Two other

Table I. — Measurements in the frontal plane

	Preop.value (mean ± SD)	Postop.value (mean ± SD)	At 1 year (mean ± SD)	At final F.O. (mean ± SD)
Cobb (°)	60.85 ± 21.1	24.21 ± 12.3	28.25 ± 10.5	28.44 ± 11.9
		p < 0.0001	p < 0.0001	p < 0.0001
Balance (mm)	-0.09 ± 19.9	4.6 ± 15.6	2.41 ± 14.5	4.44 ± 12.9
		not signif.	not signif.	not signif.
Apical translation (mm)	-19.13 ± 49.9	-5.07 ± 26	-7.42 ± 27.8	-9.42 ± 28.9
		p < 0.04	p < 0.04	p < 0.021

The symbol minus (-) means a shift to the right.

Table II. — Measurements in the sagittal plane

	Preop. value (mean ± SD)	Postop. value (mean ± SD)	At 1 year (mean ± SD)	At final F.O. (mean ± SD)
Kyphosis (°)	24 ± 13	33.4 ± 7.5	31.5 ± 7.2	30.7 ± 7.1
		not signif.	not signif.	not signif.
Lordosis (°)	-47.47 ± -18.33	-39.51 ± -18.47	-41.66 ± -17.6	-37.35 ± -27.63
T10-L2 (°)	4.86 ± 12.32	-2.60 ± 7.51	1.00 ± 16	-2.50 ± 6.12
Sag. balance (mm)	-15.48 ± 45.47	-11.19 ± 39.34	-11.19 ± 39.3	-16.57 ± 37.75

patients needed extension of the fusion area, because of curve progression. Importantly, there were no neurologic complications or implant failures such as implant breakage or dislodgement. No pseudarthrosis was noted.

DISCUSSION

Some authors, such as King (13), feel that a good result can be obtained, independently of the implant system used, if certain guidelines are followed, for example about the correct fusion level. Nevertheless, the question which instrumentation system is most efficacious remains controversial (20).

From multi-hook constructs to hybrid constructs (hooks or wires proximally and screws distally) to screw-only constructs

A major advance, after the Harrington rod, was the Cotrel-Dubousset instrumentation, a dual-rod multi-hook system, which allowed a 48% correc-

tion and immediate mobilization of the patient (17). However in 1996, Hamill *et al* (8) compared lumbar hooks with lumbar pedicle screws and found that the latter were significantly more efficient. It is without doubt that lumbar pedicle screws offer greater lumbar curve correction and better maintenance of correction than hook constructs (1). This pleaded for a hybrid construct : thoracic hooks plus lumbar pedicle screws. Moreover, adding sublaminar wires to the thoracic hooks not only allowed for apical vertebra translation to a pre-contoured rod, but also increased the chest volume (32). Sublaminar wiring was further elaborated using the Universal Clamp posteromedial translation technique (22).

The hybrid construct was however challenged by the dual-rod pedicle screw-only construct. Suk *et al* (27) were among the first protagonists. Lehman *et al* (15) noted corrections from 50% to 68%, as a function of the scoliosis type, but admitted that the sagittal thoracic alignment decreased. Corrections of 62%, 66%, 68% and 76% have been obtained by other authors (1,11,14,24).

Hybrid or screw-only ?

Kim *et al* (11,12) compared both techniques and demonstrated significantly better major curve correction and pulmonary function in the all-screw patients. But sagittal balance, lowest instrumented vertebra, operative time and SRS-24 scores were not significantly different. Lowenstein *et al* (20) came to comparable conclusions, but noted that the all-screw group demonstrated a significant decrease in kyphosis from 29.65° to 19.35°, a decrease which was not significant in the hybrid group (26.23° to 22.42°). The current study showed that hybrid instrumentation satisfactorily increased thoracic kyphosis T3T12, and that this correction was maintained. Other studies came to the same conclusion (20,26,29). Pedicle screws at the thoracic level may decrease the thoracic kyphosis (29).

So far, the all-screw construct seemed to be superior, exception made for the kyphosis. However, the aforementioned studies did not take into consideration the *preoperative flexibility* of the curve. Vora *et al* (29) compared the correction of Lenke type 1 scoliosis, taking into account the flexibility of the curve preoperatively. They used the Cincinnati Correction Index (CCI), which was expressed as the ratio : postoperative correction (%) / preoperative flexibility (%). Pedicle screw fixation did not give a better correction and had a lordosing effect on the thoracic spine, so that there was no significant benefit in using an expensive pedicle screw system.

Safety is an other variable which pleads in favor of hybrid constructs. Di Silvestre *et al* (7) drew the attention to the troublesome application of pedicle screws, especially in the thoracic spine, because the morphometry in scoliotic thoracic vertebrae differs from that of vertebrae in normal spines. Overall, the risks include neurologic injury, major vessel injury, violation of the pleura and increased radiation exposure during screw placement (6,9,10). Cadaver studies have reported frequent pedicle wall violations, between 12.5% and 43%, after thoracic pedicle screw insertion (2,6,18,28).

Pullout strength is one more variable which pleads for hybrid constructs. An experimental study, using vertebrae from human cadavers, demonstrated that the claw hook pattern in the tho-

racic spine exhibits a greater pullout strength than the pedicle screw construct (5) : claws had an average pullout strength of 577 N and screws of 309 N. This is a strong advantage when the surgeon must deal with osteoporotic bone.

Limited cost is another advantage of hybrid constructs. The average cost of a hybrid construct is significantly lower than that of an all-screw construct. Kim *et al* (11) reported a cost of 5.816 USD for 11.8 fixation points in their hook group versus 11.508 USD for 17.1 fixation points in their screw group (p < 0.001). This is probably why Winter *et al* (31) recently challenged the extreme attention given to the percent of coronal curve correction, wondering whether a few more degrees of correction are enough to justify a construct that costs twice as much as a simple hook system and that increases the risk of damage to the spinal cord or major vessels.

In the present study, no functional score was used to evaluate patient outcomes and this is a weakness of the study.

REFERENCES

1. 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.
2. Belmont PJ Jr, Klemme WR, Dhawan A, Polly DW Jr. In vivo accuracy of thoracic pedicle screws. *Spine* 2001 ; 26 : 2340-2346.
3. Cheng I, Kim Y, Gupta MC *et al*. Apical sublaminar wires versus pedicle screws – which provides better results for surgical correction of adolescent idiopathic scoliosis ? *Spine* 2005 ; 30 : 2104-2112.
4. Connolly PJ, Von Schroeder HP, Johnson GE, Kostuik JP. Adolescent idiopathic scoliosis. Long-term effect of instrumentation extending to the lumbar spine. *J Bone Joint Surg* 1995 ; 77-A : 1210-1216.
5. Cordista A, Conrad B, Horodyski M, Walters S, Rehtine G. Biomechanical evaluation of pedicle screws versus pedicle and laminar hooks in the thoracic spine. *Spine J* 2006 ; 6 : 444-449.
6. Dhawan A, Klemme WR, Polly DW Jr. Thoracic pedicle screws : comparison of start points and trajectories. *Spine* 2008 ; 33 : 2675-2681.
7. Di Silvestre M, Parisini P, Lolli F, Bakaloudis G. Complications of thoracic pedicle screws in scoliosis treatment. *Spine* 2007 ; 32 : 1655-1661.

8. **Hamill CL, Lenke LG, Bridwell KH et al.** The use of pedicle screw fixation to improve correction in the lumbar spine of patients with idiopathic scoliosis. Is it warranted? *Spine* 1996 ; 21 : 1241-1249.
9. **Hicks JM, Singla A, Shen FH, Arlet V.** Complications of pedicle screw fixation in scoliosis surgery : a systematic review. *Spine* 2010 ; 35 : E465-470.
10. **Kim YJ, Lenke LG, Bridwell KH, Cho YS, Riew KD.** Free hand pedicle screw placement in the thoracic spine : is it safe ? *Spine* 2004 ; 29 : 333-342.
11. **Kim YJ, Lenke LG et al.** Comparative analysis of pedicle screw versus hook instrumentation in posterior spinal fusion of adolescent idiopathic scoliosis. *Spine* 2004 ; 29 : 2040-2048.
12. **Kim YJ, Lenke LG, Kim J et al.** Comparative analysis of pedicle screw versus hybrid instrumentation in posterior spinal fusion of adolescent idiopathic scoliosis. *Spine* 2006 ; 31 : 291-298.
13. **King HA.** Selection of fusion levels for posterior instrumentation and fusion in idiopathic scoliosis. *Orthop Clin North Am* 1988 ; 19 : 247-255.
14. **Lee SM, Suk SI, Chung ER.** Direct vertebral rotation : a new technique of three-dimensional deformity correction with segmental pedicle screw fixation in adolescent idiopathic scoliosis. *Spine* 2004 ; 29 : 343-349.
15. **Lehman RA Jr, Lenke LG, Keeler KA et al.** Operative treatment of adolescent idiopathic scoliosis with posterior pedicle screw-only constructs : minimum three-year follow-up of one hundred fourteen cases. *Spine* 2008 ; 33 : 1598-1604.
16. **Lenke LG, Betz RR, Harms J et al.** Adolescent idiopathic scoliosis : a new classification to determine extent of spinal arthrodesis. *J Bone Joint Surg* 2001 ; 83-A : 1169-1181.
17. **Lenke LG, Bridwell KH, Baldus C, Blanke K, Schoenecker PL.** Cotrel-Dubousset instrumentation for adolescent idiopathic scoliosis. *J Bone Joint Surg* 1992 ; 74-A : 1056-1067.
18. **Liljenqvist UR, Halm HF, Link TM.** Pedicle screw instrumentation of the thoracic spine in idiopathic scoliosis. *Spine* 1997 ; 22 : 2239-2245.
19. **Lonstein JE.** Scoliosis : surgical versus non-surgical treatment. *Clin Orthop Relat Res* 2006 ; 443 : 248-259.
20. **Lowenstein JE, Matsumoto H, Vitale MG et al.** Coronal and sagittal plane correction in adolescent idiopathic scoliosis : a comparison between all pedicle screw versus hybrid thoracic hook lumbar screw constructs. *Spine* 2007 ; 32 : 448-452.
21. **Luk KD, Lu DS, Cheung KM, Wong YW.** A prospective comparison of the coronal deformity correction in thoracic scoliosis using four different instrumentations and the fulcrum-bending radiograph. *Spine* 2004 ; 29 : 560-563.
22. **Mazda K, Ilharreborde B et al.** Efficacy and safety of posteromedial translation for correction of thoracic curves in adolescent idiopathic scoliosis using a new connection to the spine : the Universal Clamp. *Eur Spine J* 2009 ; 18 : 158-169.
23. **Mielke CH, Lonstein JE, Denis F, Vandenbrink K, Winter RB.** Surgical treatment of adolescent idiopathic scoliosis. A comparative analysis. *J Bone Joint Surg* 1989 ; 71-A : 1170-1177.
24. **Potter BK, Kuklo TR, Lenke LG.** Radiographic outcomes of anterior spinal fusion versus posterior spinal fusion with thoracic pedicle screws for treatment of Lenke Type I adolescent idiopathic scoliosis curves. *Spine* 2005 ; 30 : 1859-1866.
25. **Rose PS, Lenke LG, Bridwell KH et al.** Pedicle screw instrumentation for adult idiopathic scoliosis : an improvement over hook/hybrid fixation. *Spine* 2009 ; 34 : 852-857.
26. **Sucato DJ, Agrawal S, O'Brien MF et al.** Restoration of thoracic kyphosis after operative treatment of adolescent idiopathic scoliosis : a multicenter comparison of three surgical approaches. *Spine* 2008 ; 33 : 2630-2636.
27. **Suk SI, Lee CK, Min HJ, Cho KH, Oh JH.** Comparison of Cotrel-Dubousset pedicle screws and hooks in the treatment of idiopathic scoliosis. *Int Orthop* 1994 ; 18 : 341-346.
28. **Vaccaro AR, Rizzolo SJ, Allardyce TJ et al.** Placement of pedicle screws in the thoracic spine. Part I : Morphometric analysis of the thoracic vertebrae. *J Bone Joint Surg* 1995 ; 77-A : 1193-1199.
29. **Vora V, Crawford A, Babekhir N et al.** A pedicle screw construct gives an enhanced posterior correction of adolescent idiopathic scoliosis when compared with other constructs : myth or reality. *Spine* 2007 ; 32 : 1869-1874.
30. **Webb JK, Burwell RG, Cole AA, Lieberman I.** Posterior instrumentation in scoliosis. *Eur Spine J* 1995 ; 4 : 2-5.
31. **Winter RB, Lonstein JE, Denis F.** How much correction is enough ? *Spine* 2007 ; 32 : 2641-2643.
32. **Wood KB, Schendel MJ, Dekutoski MB et al.** Thoracic volume changes in scoliosis surgery. *Spine* 1996 ; 21 : 718-723.