Anterior instrumentation (dual screws single rod system) for the surgical treatment of idiopathic scoliosis in the lumbar area: a prospective study on 33 adolescents and young adults, based on a new system of classification

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Abstract

Objectives/purpose The choice of anterior instrumentation in the treatment of lumbar scoliosis in adolescents and young adults is not a new topic for the authors. The first results achieved using the Dwyer surgical modality were reported by one of the authors followed by the results achieved using Zielke (VDS) instrumentation. Today, new techniques and new instrumentations have been developed that challenge the instrumentation choices. Here we describe how the new system of classification of scoliotic curves we developed has been used as a basis for treating idiopathic scoliosis in lumbar area in adolescents and young adults using an anterior approach.

Materials A prospective study was carried out between 1998 and 2010 at two hospital centers on 33 adolescents and young adult with idiopathic lumbar scoliosis involving curves of three kinds, on whom surgical treatment was performed using a single solid rod. Topography of curves: our system of classification includes curves corresponding to the following three type of scoliosis: Type K I: double thoracic and lumbar curves (lumbar predominant) scoliosis (17 cases) mean age 16 years all female patients. Mean Cobb angle of lumbar curve 41°. Mean Cobb angle of thoracic curve 28°. The lumbar curve was left hand convex in 15 cases and right hand convex in 2 cases. Horizontal tilting of L4 mean value 22°. C7 offset mean value 3 cm. Type K IV A: unbalanced thoracolumbar scoliosis (13 cases) mean age 17 years, ten female patients and three male patients. Mean Cobb angle of thoracolumbar curve 39°. The thoracolumbar curve was left hand convex 4 times

and right hand convex 9 times. Horizontal tilting of L4 mean value 18°. C7 offset mean value 2.5 cm. Type K VI A: real lumbar (three cases). Age: 17, 15 and 13 years; all female patients. Cobb angle of the lumbar curve 66°, 29° and 70° (all LH convex). Horizontal tilting of L4: 40°, 20° and 46°. C7 offset: 7 cm, 1 cm and 4 cm.

Methods Surgical instrumentation: We used the EUROS AZUR anterior instrumentation for all the procedures. Cages have been used on five patients at the lower stages. Number of vertebrae instrumented: mean five vertebrae. The patients did not wear postoperative orthosis. Mean duration of procedure: 3 h 50 min. Mean blood loss: 350 cm³.

Results Type K I scoliosis (17 cases): Mean follow-up: 6 years. Correction of the lumbar curve Cobb angle: the mean angle has been corrected from 41° to 21°. Number of vertebrae instrumented: 4:6 times and 5:11 times. Correction of the upper thoracic curve Cobb angle: mean angle corrected from 28° to 19°. Correction of L4 horizontal tilting: mean residual was 7°. Correction of C7 offset: mean 0.7 cm. Type K IV A scoliosis (13 cases): mean follow-up: 4 years. Correction of the lumbar curve Cobb angle: the mean angle has been corrected from 39° to 16°. Mean number of instrumented vertebrae: 5 (4:4 times, 5:6 times and 6:3 times.) Correction of L4 horizontal tilting: mean residual 5°. Correction of C7 offset: mean 0.7 cm. Type K VI A scoliosis (three cases): mean follow-up: 7, 2 and 4 years; Correction of the lumbar curve Cobb angle: the angles have been corrected from 66° to 15°, from 29° to 11° and from 70° to 28°. Number of instrumented vertebrae: 5, 4 and 6. Correction of L4 horizontal tilting: residual tilting of 8°, 7° and 17°. Correction of C7 offset: 1 cm, 0 cm and 1 cm.

Complications There has been no report early or late septic or vascular or neurological complications. Instrumentation

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failure: there were three cases of screw breakage, all occurred on the lowest implant. Revision surgery was undertaken in both cases, only the last plate needed to be replaced and the rod could be kept without any other modification of the construct. In both cases, fusion has been achieved without any loss of correction. The mean loss of correction of the main curve was 2.5° for the three series.

Conclusions Anterior instrumentation of lumbar idiopathic scoliosis gives highly satisfactory morphological and functional results, since the lumbar musculature is spared and the instrumentation placed at the apex of the curvature has selective effects. Despite our preference and that of other surgeons throughout the world for anterior instrumentation, we are still a minority in comparison with the users of posterior instrumentation. There are several reasons for this reticence, including surgeons' training and ideas about pedicular screw fixation, but the main reason has been the lack of a sufficiently exact system of classification. Previous comparative studies between the anterior and posterior approaches have been biased by the use of an excessively restrictive mode of classification (lumbar/thoracolumbar) of the curves. Real lumbar scoliosis, unbalanced thoracolumbar scoliosis and thoracic and lumbar double curve (lumbar predominant) scoliosis should be properly defined before being compared.

Keywords Adolescent idiopathic scoliosis · Anterior instrumentation · Trunk balance · Sagittal balance · Shoulder balance · Curve's classification

Introduction

The authors of this paper have been using anterior instrumentation for some time to treat scoliosis in adolescents and young adults: one of them used the Dwyer procedure [11] to treat lumbar idiopathic scoliosis back in 1978 [30], and in 1996 [3] presented the results obtained using Zielke (VDS) [41] instrumentation. Today, new techniques and new methods of instrumentation have been developed that challenge the instrumentation choices. Here we describe how the new system of classification of scoliotic curves we developed has been used as a basis for treating idiopathic scoliosis in lumbar area in adolescents and young adults using an anterior approach, and to ensure that this was the most suitable strategy in each case.

Materials

A prospective study was carried out between 1998 and 2010 at two hospital centers on 33 adolescents and young adults (<30 years) with idiopathic lumbar scoliosis

involving curves of three kinds, on whom surgical treatment was performed using the same method of anterior instrumentation (involving a single solid rod).

Topography of curves: our system of classification [4] includes curves corresponding to the following three types of scoliosis:

- Type K I: double thoracic and lumbar curves (lumbar predominant),
- Type K IV A: unbalanced thoracolumbar curves,
- Type VI A: real lumbar curves.

Lumbosacral scoliosis (K VI B), which borders on idiopathic and malformative scoliosis, was excluded from this list (Fig. 1).

Type K I scoliosis (17 cases)

Mean age 16 years (range 15–17 years); all the patients in this group were female.

Mean Cobb angle of the lumbar curve: 41° (range 29° – 64°).

Number of vertebrae (V) involved in the lumbar curve: mainly 6–7 (5 V in two cases; 6 V in seven cases; 7 V in six cases; 8 V in two cases).

The end vertebrae ranged from T9 to L4. Proximal end vertebrae: (T9 in three cases, T10 in six cases, T11 in seven cases, T12: once); distal end vertebrae: (L3 in 2 cases and L4 in 15 cases). The apex vertebra ranged between T12 and L2: (T12 in two cases, T12–L1 in two cases, L1 in six cases, L1–L2: in six cases and L2 in one case). The lumbar curve was left hand convex in 15 cases and right hand convex in 2 cases.

Mean Cobb angle of the thoracic curve: 28° (range 15° – 42°).

Mean number of vertebrae involved in the thoracic curve 7 (5 V in two cases, 6 V in three cases, 7 V in seven cases and 8 V in five cases).

End vertebrae ranged from T3 to T12: proximal end vertebrae (T3 in three cases, T4 in seven cases, T5 in six cases, T6 in one case); distal end vertebrae (T9 in one case, T10 in six cases, T11 in seven cases, T12 in one case). The apex vertebra ranged between T7 and T8: (T7 in eight cases, T7–T8 in one case, T8 in eight cases). The thoracic curve was right hand convex in 15 cases and left hand convex in 2 cases.

Horizontal tilting of L4: mean value 22° (range 14° – 35°).

Lateral translation (C7 offset): mean value 3 cm (range 1–6 cm).

Lumbar lordosis: mean value 52° (range 30° – 66°). Thoracic kyphosis: mean value 37° (range 26° – 48°).

Two patients presented with a short junctional thoracolumbar kyphosis. S1 sacral plate tilting (sacral slope):

Fig. 1 The ten curves of our classification, in red color the three types selected for anterior instrumentation

mean value 35° (range 24°–65°). Shoulder balance: practically normal in eight cases. A shoulder offset of 0.5–2 cm was measured in nine cases.

Type K IV A scoliosis (13 cases)

Mean age: 17 years (range 13–28 years): ten of the patients in this group were female and three were male.

Mean Cobb angle of the thoracolumbar curve: 39° (range 22°–59°).

Number of vertebrae involved in the curve: 10–11 (8 V in two cases, 10 V in three cases, 11 V in four cases, 12 V in four cases). The end vertebrae ranged from T4 to L4: proximal end vertebrae (T4 in five cases, T5 in one case,

T6 in four cases, T7 in one case, T8 in two cases); distal end vertebrae (L3 in nine cases, L4 in four cases).

The apex vertebra ranged between T11 and L1 (T11–T12 in four cases, T12 in three cases, T12–L1 in five cases, L1: in one case).

The thoracolumbar curve was left hand convex in four cases and right hand convex in nine cases (in the three male patients, the curve was RH convex).

Horizontal tilting of L4: mean value 18° (range 10°–25°).

C 7 offset: mean value 2.5 cm (range 1–4.5 cm). Lumbar lordosis: mean value 55° (range 40°–78°).

Thoracic kyphosis: mean value 30° (range 15°–38°). Sacral slope: mean value 40° (range 24°–54°).

Table 1 Patients demographics and coronal data

	No.	Ages	Sex	Convex side main curve	Main curve	Numb verteb	Apex verteb	Fusion verteb	Numb verteb fused
K I	1	14	F	Left	T10–L3	6	T12	T10–L2	5
	2	15	F	Left	T9–L4	8	L1	T11–L3	5
	3	17	F	Left	T11–L4	6	L1–L2	T12–L3	4
	4	16	F	Left	T11–L4	6	L1–L2	T12–L3	4
	5	15	F	Left	T10–L4	7	L1	T11–L3	5
	6	17	F	Left	T10–L4	7	T12–L1	T11–L3	5
	7	16	F	Right	T11–L4	6	L1–L2	T12–L3	4
	8	15	F	Left	T9–L4	8	T12–L1	T11–L3	5
	9	15	F	Left	T11–L4	6	L1–L2	T12–L3	4
	10	16	F	Left	T11–L4	6	L1–L2	T12–L3	4
	11	18	F	Left	T10–L4	7	L1	T11–L3	5
	12	14	F	Left	T9–L3	7	T12	T10–L2	5
	13	17	F	Left	T12–L4	5	L2	T12–L4	5
	14	16	F	Right	T10–L4	7	L1	T11–L3	5
	15	17	F	Left	T10–L4	7	L1	T11–L3	5
	16	16	F	Left	T11–L4	6	L1	T12–L3	4
	17	16	F	Left	T11–L3	5	L1–L2	T11–L3	5
K IV A	18	13	F	Left	T4–L3	12	T12–L1	T11–L3	5
	19	21	M	Right	T4–L3	12	T12–L1	T10–L3	6
	20	13	F	Right	T5–L3	12	T12	T10–L3	6
	21	14	F	Right	T4–L3	11	T11- T12	T10–L2	5
	22	16	F	Left	T8–L3	12	T12–L1	T11–L3	5
	23	13	F	Right	T6–L4	8	T12–L1	T11–L3	5
	24	28	M	Right	T6–L4	11	T12	T10–L3	6
	25	17	F	Right	T6–L3	10	T12–L1	T12–L3	4
	26	21	F	Right	T6–L3	10	T11–T12	T10–L2	5
	27	16	F	Left	T8–L4	8	L1	T12–L3	4
	28	16	M	Right	T4–L3	12	T11–T12	T10–L2	5
	29	16	F	Right	T4–L3	11	T12	T11–L2	4
K VI A	30	16	F	Left	T7–L4	10	T11–T12	T12–L3	4
	31	17	F	Left	T11–L5	7	L1–L2	T11–L3	5
	32	15	F	Left	T12–L4	5	L2	T12–L3	4
	33	13	F	Left	T10–L4	7	T12–L1	T10–L3	6

The shoulder balance was practically normal in one case. 12 cases had a shoulder offset ranging from 0.5 to 2.5 cm (mean value 1 cm).

Type K VI A scoliosis (3 cases)

Age: 17, 15 and 13 years; all the patients in this group were female.

Cobb angle of the lumbar curve: 66°, 29° and 70° (all these curves were LH convex).

Proximal end vertebra: T11, T12 and T10.

Distal end vertebra: 5, L4 and L4.

Apex vertebra: L1–L2, L2 and T12–L1. Horizontal tilting of L4: 40°, 20° and 46°. C 7 offset: 7, 1 and 4 cm.

Lordosis: 52°, 46° and 30°.

Thoracic kyphosis: 30°, 35° and 27° (the last case presented with a junctional kyphosis between the thoracic and lumbar curves). Sacral slope: 38°, 28° and 26°. Shoulder balance: LH shoulder 2 cm lower in the first and third cases, and LH shoulder 1 cm higher in the second case (Table 1).

Methods

A transpleural and subperitoneal thoraco-phreno–Laparotomy was performed, with the patient positioned in the lateral decubitus position, and the same surgeon performed the instrumented surgical correction on the scoliosis. This surgery involves the use of a thoracic drain, which is removed on day 2.

Surgical instrumentation: EUROS AZUR anterior instrumentation was used in all these procedures. This is a specific instrumentation, and the authors were involved in the design of the anterior elements used to treat lumbar scoliosis. It comprises plates, which have to be secured to the lateral side of the vertebral body by means of two screws introduced in the triangulation plane. The base holding the rod is mobile relative to the plate. The 6 mm rod, which is fairly elastic, is then secured to the vertebral plates. It is worth noting that the rod is positioned very posteriorly relative to the sides of the vertebral body. This is essential for the corrective maneuvers to succeed. It is also worth noting that this position of the rod relative to the vertebral body makes it possible to perform bending in situ during these maneuvers, and thus prevents the over-correction liable to occur when the rod stops rotating. The initial stainless steel material (which was used on the first 5 patients) was replaced by titanium material in the other 28 other patients. Cages have been recently used on five patients at the lower vertebral levels.

Bony fusion material: morselized ribs and bone substitute in addition.

Number of vertebrae instrumented: five vertebrae in 18 case, four vertebrae in 2 cases, six vertebrae in 4 cases. **Last vertebra instrumented:** L4 in 1 case; L3 in 27 cases; L2 in 5 cases (4 of whom belonged to the K IV A group). The patients were not fitted with any postoperative orthosis. **Mean duration of procedure:** 3 h 50 min (this is 1 h shorter on average than with the posterior approach). **Mean blood loss:** 350 cm³ (Table 2).

Results

Type K I scoliosis (17 cases)

Mean follow-up time: 6 years (range 2–13 years).

Correction of the Cobb angle of the lumbar curve: the mean angle was corrected from 41°–21° (the residual angle ranged from 8°–41°).

Number of vertebrae instrumented: 4 in 6 cases and 5 in 11 cases.

Proximal end vertebra instrumented: T10 in 2 cases, T11 in 9 cases and T12 in 6 cases.

Distal end vertebra instrumented: L2 in 2 cases, L3 in 14 cases and L4 in one case.

Correction of the Cobb angle of the upper thoracic curve: the mean angle was corrected from 28°–19° (range 10°–38°) (Fig. 2).

Correction of L4 horizontal tilting: the mean residual tilting was 7° (range 15°–0°).

Correction of C 7 offset: mean correction was 0.7 cm (range 2.5–0 cm).

Modification of lumbar lordosis: the mean residual lordosis was 42° (range 27°–54°). **Modification of thoracic kyphosis:** the mean residual kyphosis was 32° (range 23°–40°). **Spontaneous correction of the two junctional kyphosis.**

Modification of the sacral slope: the mean residual angle was 29° (range 22°–55°).

Shoulder balance was restored to normal in 14 cases, and in three cases, remaining unbalance ranged from 0.5 to 1 cm (Table 3).

Type K IV A scoliosis (13 cases)

Mean follow-up time: 4 years (range 1–9 years).

Correction of the Cobb angle of the lumbar curve: the mean angle was corrected from 39° to 16° (the residual angle ranged from 7° to 37°).

Mean number of vertebrae instrumented: 5 (4 in 4 cases, 5 in 6 cases and 6 in 3 cases).

Highest vertebra instrumented: T10 in six cases, T11 in four cases and T12 in 3 cases.

Lowest vertebra instrumented: L2 in four cases and L3 in nine cases.

Correction of L4 horizontal tilting: the mean residual tilting was 5° (range 14°–0°).

Correction of C 7 offset: mean residual offset was 0.7 cm (range 2.5–0 cm).

Modification of lumbar lordosis: the mean residual lordosis was 47° (range 32°–60°).

Modification of thoracic kyphosis: mean residual kyphosis was 28° (range 22°–36°).

Modification of the sacral slope: the mean angle obtained was 39° (range 22°–50°).

Shoulder balance: restored to normal in seven cases, and in six cases, there was a residual shoulder imbalance ranging from 0.5 to 1 cm (Fig. 3).

Type K VI A scoliosis (3 cases)

Follow-up times: 7, 2 and 4 years

Correction Cobb angle of the lumbar curve: the Cobb angles were corrected from 66° to 15°, from 29° to 11° and from 70° to 28°.

Number of vertebrae instrumented: 5, 4 and 6.

Highest vertebra instrumented: T11, T12 and T10.

Table 2 Results of the instrumented curves (main curve angles preoperatively postoperatively and sagittal balance)

	No	Main curve Cobb angle (°)		Lumbar lordosis (°)		Sacral slope (°)		Thoracic kyphosis (°)		Follow-up Years
		Pre-op	Post-op	Pre-op	Post-op	Pre-op	Post-op	Pre-op	Post-op	
K I	1	35	13	57	54	30	37	48	37	13
	2	45	32	48	46	26	25	27	28	13
	3	34	20	52	27	35	25	39	25	2
	4	35	15	41	35	36	33	32	27	5
	5	52	12	49	40	28	22	42	32	2.5
	6	64	41	46	41	24	35	45	32	9
	7	47	31	45	50	32	25	48	40	9
	8	53	29	46	49	36	30	45	38	6
	9	31	23	64	45	50	34	35	30	4
	10	49	30	30	30	29	30	35	30	5
	11	35	15	48	38	30	24	35	32	5
	12	48	18	68	56	65	55	29	27	8
	13	29	14	64	33	34	20	35	32	2
	14	37	16	66	38	40	24	40	39	5
	15	29	14	50	54	34	28	40	39	3
	16	30	18	60	39	46	28	35	32	6
	17	40	8	47	39	27	24	26	25	4
K IV A	18	34	9	40	44	37	34	15	24	4
	19	38	15	53	44	34	35	32	32	1
	20	44	11	63	59	45	50	35	31	8
	21	40	9	61	58	49	45	28	25	9
	22	44	19	43	39	41	45	32	22	4
	23	47	24	45	40	35	45	27	25	3
	24	59	37	59	55	38	35	22	23	3
	25	40	20	46	32	24	22	32	32	7
	26	30	11	54	43	32	28	27	25	1
	27	36	7	58	41	54	42	32	27	2
	28	39	16	56	35	35	32	35	36	5
	29	38	22	59	57	50	47	26	25	5
K VI A	30	22	12	78	60	48	43	38	34	1
	31	66	15	52	44	38	42	30	33	7
	32	29	11	46	52	28	27	35	36	2
	33	70	28	30	43	26	35	27	24	4

Measures of post-op Cobb angles are on the same vertebrae of pre-op Cobb angles

Lowest vertebra instrumented: L3 in all 3 cases.

Correction of L4 horizontal tilting: the residual tilting was 8°, 7° and 17°.

Correction of C 7 offset: reduced to 1 cm, 0 cm and 1 cm.

Modification of the lumbar lordosis: residual lordosis was 44°, 52° and 43°.

Modification of the thoracic kyphosis: residual kyphosis was 33°, 36° and 24°.

Spontaneous correction of junctional kyphosis in the last case. Modification of the sacral slope: angle obtained was 40°, 20° and 46°.

Shoulder balance: restored to normal in all three cases (Fig. 4) (Table 4).

Complications

There were no reports of pleural effusion, early or late septic complications, or vascular or neurological complications (all the intercostal and lumbar arteries and veins were ligated or coagulated on the lateral face of the instrumented vertebrae).

Instrumentation failure: there were three cases of screw breakage (titanium: series KI), all of which occurred on the

Fig. 2 Case N° 5, Type K I scoliosis, **a, d**: pre-op X-rays (Risser 2), **b** immediate post-op, and **c, e** 2.5 years follow-up (Risser 4), spontaneous correction of thoracic curve and shoulders balance. **f–i** pre- and post-op 2 years follow-up the cosmetic aspect

Table 3 Results of the non instrumented thoracic curve on type K I

	No.	Apex thor curve	Sup end vert	Inf end vert	Numb vert	Cobb angle pre-op (°)	Cobb angle post-op (°)	Follow-up (years)
K I	1	T7–T8	T4	T10	7	24	16	13
	2	T7	T4	T9	7	32	26	13
	3	T8	T5	T11	7	24	14	2
	4	T8	T5	T11	7	30	25	5
	5	T7	T4	T10	7	26	15	2.5
	6	T7	T3	T10	8	42	38	9
	7	T8	T6	T11	5	30	24	9
	8	T7	T4	T9	6	31	25	6
	9	T8	T4	T11	8	15	14	4
	10	T8	T5	T11	7	31	30	5
	11	T8	T5	T10	6	23	10	5
	12	T7	T4	T9	6	30	18	8
	13	T8	T5	T12	7	27	16	2
	14	T7	T3	T10	8	35	21	5
	15	T7	T3	T10	8	28	15	3
	16	T7	T4	T11	8	16	23	6
	17	T8	T4	T11	5	38	23	4

lowest implant (in one case on L2; in two cases on L3). In two of these cases, the construct involved only four vertebrae, and in the other case, it involved five vertebrae. The failures occurred 9, 10 and 11 months postoperatively. Since these patients were suffering from pseudarthrosis, revision surgery was undertaken via the previous skin incision, in addition to a short lumbotomy, since only the last plate needed to be replaced and the rod could be kept in place without having to change the construct in any other way. The interbody space was refreshed and grafted using autogenous cortico-cancellous grafts harvested from the iliac crest and fitted in compression on the lowest vertebra. In two cases, fusion was achieved without any loss of correction. In the third case, since the breakage was asymptomatic and did not induce any loss of correction, it was decided not to re-operate yet. The mean loss of correction of the main curve was 2.5° in all three types of patients. The loss of correction was not correlated to a distal or proximal adding-on phenomenon. It seems correlated to spontaneous correction of trunk balance.

Discussion

Advantage of the system of classification used

If the three types of curves present in these patients had been analyzed all together as has usually been done in previous studies on this topic, it would not have been

possible to detect the similarities and the differences of each group. The similarities between the three types of curve focused on the age distribution, the mean Cobb angle, the L4 tilting angle and the lateral translation. The main point in common observed was the very low level of the apex vertebrae present in all three types (between the T12–L1 disk and L2). A difference of only one vertebral level was observed between types K I and K IV A in the position of the apex vertebra. The main differences observed focused on the number of vertebrae involved in the lumbar curve: they averaged 6–7 in the K I group and 10–11 in the K IV A group. The convex side of the lumbar curve differed significantly between the two main groups: it was located on the left hand side in almost all the K I patients (14/16) and on the right hand side in most of the K IV A patients (9/13). Patients' gender: all the present K I type patients were female; but the thirteen K IV A type patients included three males (who presented with RH convex lumbar curves). There were no thoracic curves in the patients in groups K IV A and KVI A. In all three groups, it was essential to determine the lowest position of the apex vertebra in order to understand the natural history of the condition and determine the most suitable surgical strategy.

It is worth recalling the natural history of these three types of curve since it is directly linked to the therapeutic indications. The biomechanical evolution of this scoliosis is different from that of thoracic scoliosis, as Graf's three-dimensional reconstructions have shown [12]. In terms of their evolution, all these curves lead at a fairly early age

Fig. 3 Case N° 26, Type K IV A scoliosis, **a, c** pre-op X-rays, **b, d** one year post-op follow-up. **e–h** pre- and post-op 1 year follow-up the cosmetic aspect

(as from the age of 30) to a disk failure that usually starts at the L3–L4 disk before extending to all the disks involved in the lumbar curve. L3–L4 rotatory dislocation, which is highly invalidating, accounts for 75 % of the surgical procedures performed on adults with lumbar scoliosis (25 % of surgical procedures, for degenerative so-called “de novo” form). Since these three types of curves are poorly tolerated in adulthood, it is necessary to prevent them from evolving by resorting to either conservative treatment or surgery.

Conservative treatment

Experience has shown that conservative treatment is not very effective, mainly because the diagnosis is made too late since the deformity is barely noticeable at first, whereas it evolves very fast during puberty. Orthosis-based conservative treatment is easy to implement, because the lumbar curves are always more flexible than the thoracic curves. The main problem is how to maintain the vertebral derotation during the removal of the orthosis. In female

Fig. 4 Case N° 31, Type K VI A scoliosis, **a, c** pre-op X-rays, **b, d** post-op X-rays. **e–h** pre- and post-op 4 years follow-up the cosmetic aspect

adolescents with mature bones, a residual Cobb angle of 25° can be taken to be a satisfactory result in the case of thoracic scoliosis, but not in that of lumbar scoliosis, especially if the apex vertebra is still significantly rotated. Unfortunately, this residual curve will continue to evolve as naturally as a non-treated curve. The ideal solution would be to target the zero-degree option [10], but this is possible only with young children in whom the treatment is initiated when the Cobb angle is no greater than 20°, which is possible in very few cases.

Surgical treatment

One of the main reasons for performing anterior instrumentation on the patients in this study was the low position of the apex vertebra, which made it possible to use short constructs on all three groups. Comparisons between the results obtained on groups K I and K IV A showed the existence of both similarities and differences.

Similarities: the mean correction of the Cobb angle of the main curve obtained 16°–21°. Likewise, the correction of the L4 horizontal tilting and that of the lateral translation were very similar. At the morphological level, the unsightly waist-clamp asymmetry was corrected in all three

groups of patients. The quality of the functional results obtained was also identical. Differences: in the K IV A group, a one-level upward offset of the instrumentation (a significant offset, since it involved the proximal and distal end vertebrae) occurred. This difference is not of great importance in comparison with that between the number of vertebrae involved in the curve. The proponents of anterior instrumentation have report several strategic differences. The choice of instrumentation can differ in terms of its elasticity or rigidity and can consist of either one [5, 8, 16, 39] or two rods [1, 7, 13, 17, 34], possibly associated with cages [7, 37]. The stiffness of the two-rod construct decreases the risk of hardware breakage. In the present series, three cases of screw breakage (10 %) occurred. The use of cages around the last two vertebral spaces in the five last cases of our series should prevent breakage in principle (too short follow-up), although some authors have concluded that these devices are useless, and others have stated that they do not prevent the occurrence of pseudarthrosis [21]. It is worth noting that the two cases of revision surgery were very simple and left no sequelae. There exists no perfect kind of instrumentation. A compromise must always be found between elasticity, which favors fusion, and rigidity, which stabilizes the arthrodesed segment. The

Table 4 Results of the instrumented curves (coronal balance)

	No.	Tilt L4 (°)		C7 offset (cm)		Shoulders balance (cm)		Follow-up (years)
		Pre-op	Post-op	Pre-op	Post-op	Pre-op	Post-op	
K I	1	19	0	2	0	0	0	13
	2	25	11	1	0	0	0	13
	3	18	13	2.5	1	0	0	2
	4	17	0	2.5	0	0	0	5
	5	31	4	3	0	+1L	0	2.5
	6	35	11	6	2.5	0	0	9
	7	28	10	1	0	+1L	0	9
	8	27	15	2	0.5	0	0	6
	9	17	10	5	0	−1L	0	4
	10	30	15	3	1	−0.5L	0	5
	11	17	5	4	1	+1L	0	5
	12	26	5	4	0.5	0	0	8
	13	17	0	2.5	0	+1L	0	2
	14	20	0	2.5	0	+2L	1	5
	15	14	4	3.5	1.5	−1.5L	−0.5L	3
	16	16	6	3	1	0	0	6
	17	25	6	4	2	+1L	+0.5L	4
K IV A	18	18	8	2.5	2.5	+0.5L	0	4
	19	20	8	3	0.5	−2L	0	1
	20	22	4	2	0.5	+0.5	0	8
	21	15	2	2	0	+1L	+0.5L	9
	22	20	7	2	0.5	−1L	0	4
	23	24	8	2.5	1.5	+1L	0	3
	24	25	14	3	0.5	+2.5L	+1L	3
	25	20	8	1.5	0	+1L	+0.5	7
	26	15	0	2	0	+1.5L	+0.5L	1
	27	17	3	4.5	0.5	−1L	0	2
	28	13	5	1.5	0.5	+1L	+1L	5
	29	10	0	2.5	0.5	0	0	5
	30	17	1	4	1	−1L	+0.5L	1
K VI A	31	40	8	7	1	−2L	0	7
	32	20	7	1	0	+1L	0	2
	33	46	17	4	1	−2L	0	4

Shoulders balance : L+ or L− left shoulder position

instrumentation makes in situ bending possible to complete the correction at the end of the procedure. This explains the choice of approach made here. The extent of the construct varies from one author to another. Some authors have used conventional constructs, which extend from one neutral vertebra to another [1, 8, 33, 39], while others authors have used very short constructs. The surgeons who prefer the use of short constructs in line with J. Hall [5, 6, 19, 23] recommend that an over-correction should be made at the apex of the curvature, usually including three vertebrae, using the *bone-on-bone* technique: no long-term follow-up results are yet available on this procedure. Were there any

cases in which the construct should have been longer? [31, 32] This is why we have been using an intermediate method, in which shorter or longer constructs are adopted depending on the specificities of the curvature. We do not include L4, even if the latter is involved in the curve since spontaneous postoperative correction of L4 tilting generally occurs. As regards the proximal limit of the instrumentation, unbalanced thoracolumbar scoliosis (K IV A) may require particularly long constructs reaching as far as T9 or T8 (six vertebrae were instrumented in three patients) or shorter ones (four vertebrae were instrumented in four patients). If we consider the X-ray results of our patients

with a critical eye: in the type K I, may be, we could save one level in six cases (4 V instead 5) and avoid the only one fusion to L4; in the type K IV A, may be, we could save one level in two cases (4 V instead 5) and in two cases extend one level to the upper part of the instrumentation. The curve's topography is not the only decisive parameter, since the patient's age, the severity and the rigidity of the curve may make it necessary to extend the construct. In the K I group, there is a risk of acting too proximally, even by one vertebral level, and thus preventing the spontaneous correction of the thoracic curve.

Discussion: the choice between anterior or posterior instrumentation for treating these three types of scolioses

The development of anterior instrumentation for the surgical treatment of idiopathic scoliosis is nothing new. The advent of Dwyer instrumentation at the beginning of the seventies was something of a revolution, as were the previous Harrington instrumentation and the Cotrel-Dubousset (C.D.) instrumentation developed 10 years later. The first results achieved using the Dwyer procedure [18, 22, 30] fueled a lot of enthusiasm, especially since the Harrington procedures had proved to be rather unsatisfactory for dealing with lumbar scoliosis. Zielke (VDS) improved the Dwyer technique and contributed to the uptake of anterior instrumentation [25, 28, 29, 42]. As early as the beginning of the 1980s, the arrival of C.D. instrumentation set off a new wave of enthusiasm for its potential use in posterior instrumentation [36], and this was accompanied by a loss of interest in the anterior approach, which we criticized in a somewhat provocative article [2]. Several surgeons then improved the anterior constructs to make them stiffer and more efficient [13, 14, 16, 17, 33, 37]. But almost simultaneously, pedicular screws were developed: the controversy was fueled anew [26] and is still raging today, for both objective and subjective reasons. This controversy stems mainly from the problems, which arise when comparing various series.

The need for a more exact classification of scoliotic curves

Since there exists no proper classification of scoliotic curves (King's system of classification does not include the specificities of lumbar scoliosis and neither does Lenke's system of classification, which is based on arbitrary vertical and horizontal lines), comparisons are bound to be highly approximative. In a recent article, we attempted to define these curves [4] in order to be able to perform comparative studies on various series in the future. The present state of confusion will continue, however, as long as the general terms lumbar and thoracolumbar scoliosis are kept.

Lumbosacral scoliosis which are borderline to idiopathic and malformative curves should be separately analyzed. It is necessary to differentiate between balanced and unbalanced thoracolumbar curves. Balanced thoracolumbar curves behave like simple thoracic ones and can be treated by means of posterior instrumentation, which gives excellent results. In the case of unbalanced curves, the correction of the trunk translation and the postoperative shoulder balance achieved using various types of instrumentation should be compared. In the case of scoliosis with a double thoracic and lumbar (lumbar predominant) curve, corresponding to the King I category, which we have kept in our system of classification, comparisons have shown the existence of major differences, depending on the procedure used. Similar curves of this kind have been corrected by instrumenting three vertebrae using the anterior approach [24] or thirteen vertebrae using the posterior approach [9]. In the case of a real moderate, flexible lumbar scoliosis (without any thoracic scoliotic component), this curve can be operated on using either the anterior or posterior approach from the mechanical point of view, with similar objective results in terms of the number of vertebrae instrumented, the quality of the correction and that of the frontal or sagittal balance of the spine. From the functional point of view, comparisons are more subjective: how can the superiority of a procedure preserving the posterior musculature be measured? Even if this were possible, although the posterior spinal musculature has become a topic of interest since it is involved in the development of mini-invasive surgery, it is worth recalling that the anterior approach is the very best way of achieving this result.

The need for a precise analysis of the evolution of frontal and sagittal segments adjoining the instrumented curve

In patients fitted with short constructs based on posterior instrumentation alone, Shu-Hua Yang [35] has mentioned the possibility that postoperative proximal hyperkyphosis may develop. However, this well-known risk is directly linked to the deterioration of the musculature of the thoracolumbar hinge. No kyphotic deterioration has been observed above our constructs. The improvement in the correction of the main curve that the first users of anterior instrumentation—including ourselves [3, 30]—insisted on [18, 25, 28] is actually a rather secondary advantage. This improvement has often been over-assessed, since only the vertebral segment instrumented was taken into account, and not the main curve itself. The lumbar and thoracic curvatures end up by balancing each other (in our K I series, the mean postoperative lumbar curve was 21° and the thoracic curve was 19°). The advocates of the posterior approach have expressed divergent opinions as to which strategy should be adopted depending on the L4

tilting observed [20, 34], which has not occurred among those using the anterior approach. This makes the anterior approach attractive over posterior instrumentation in which in most cases L4 would have been chosen as the last instrumented vertebra. Lastly, the results have not always been presented very objectively. In the book *IDIOPATHIC SCOLIOSIS* (The Harms study group treatment guide) [27] which advocates the posterior approach, the example of anterior instrumentation giving poor results cited (on page 230) was due to the wrong vertebral level being selected for the installation of the implants, and the two examples given on pages 236 and 237 are not typical of the best applications of anterior instrumentation. The cost of short fusion in posterior instrumentation is the distal adding-on; this is not the same problem in anterior instrumentation. The conclusions reached by Wang [40] in the only comparative prospective study published so far, in which the anterior and posterior approaches were applied to two identical/perfectly matched cohorts of patients, seem to be in favor of the anterior approach, pending further information about the longer term evolution of the disks subjacent to posterior arthrodesis (this is the main weak point of posterior instrumentations). In a recent retrospective comparative study Tao [38] concluded: “anterior solid rod-screw instrumentation results in shorter fusion segments and better sagittal alignment and better quality of life than posterior pedicle screw instrumentation in patients with Lenke type 5 AIS”. These two studies are interesting, since the two surgeons in question had acquired similar experience with both approaches. It is certainly questionable whether all surgical teams can boast this dual experience. Some surgeons have not been trained to use the anterior approach [15], while others surgeons did not use it for lack of motivation, since the orthopaedic and neurosurgical training required leaves little time for cervical, thoracic and abdominal training.

Our opinions about this controversy

At the end of this short and necessarily incomplete discussion, to carry out this analysis we have our short- and long-term results. Short-term results: if we compare the functional results, we can see that the quality of the functional muscle performances depends directly on the all the muscle and nerve fibres in the posterior spine have been spared. When this is the case, the natural lordosis is preserved and the spine and shoulders can more easily be balanced since there will be no stresses at the ends of the construct. Long-term results: we operated on our first patients in 1974 (Dwyer instrumentation), and we have been following up 3 patients (two females, one male, curves ranging from 45° to 65°) for 37 years now. Control

X-rays were recently carried out, no L3–L4 dislocation or loss of disk height was observed at this level and no distal adding-on. Anterior instrumentation can be definitely said to have positive effects on the evolution of the disease. It should be noted that with Dwyer instrumentation—even if the screws are positioned as posteriorly as possible—it is not possible to restore a proper lordosis, which is comparable to that obtained with the latest materials. Anterior instrumentation of patients with lumbar scoliosis results in spines that remain silent for several years. The quality of these long-term results confirms the validity of this strategy. One last problem remains to be solved, which focuses on the threshold surgical indications, which should be applied in the case of adolescents and young adults, which depend on the extent of the deformity. Adults’ poor tolerance of lumbar curves—such as we have defined them—with a Cobb angle ranging between 25° and 35°, along with a severe rotation of the apex vertebra, the aggravation of which often requires late surgery, raises questions about the thresholds of the surgical indications. The sequelae of patients who have undergone early preventive surgery will be relatively slight in comparison with the highly unpredictable results obtained on older patients. Anterior instrumentation seems to provide the best solution in these threshold cases (nine of the cases in our three groups had a Cobb angle of less than 35°), although lowering the surgical threshold based on our experience and our convictions is liable to expose us to the risk of being criticized because no consensus has been reached on these issues. A long-term assessment tool is therefore badly needed, and a national lumbar scoliosis register of a similar kind to the existing hip and knee registers is also required.

Conclusions

Anterior instrumentation of lumbar idiopathic scoliosis gives highly satisfactory morphological and functional results, since the lumbar musculature is spared and the instrumentation placed at the apex of the curvature has selective effects. There is still some controversy as to whether these constructs should be short (involving three vertebrae) or much longer. The aim of this paper was to show that the choice of construct should not be based on a school of thought but should rather be made depending on the type of curve, its stiffness and the patient’s age. However, despite our preference and that of other surgeons throughout the world for anterior instrumentation, we are still a minority in comparison with the users of posterior instrumentation. As mentioned above, there are several reasons for this reticence, including surgeons’ training and ideas about pedicular screw fixation, but the main reason has been the lack of a sufficiently exact system of

classification. Previous comparative studies between the anterior and posterior approaches have been biased by the use of an excessively restrictive mode of classification (lumbar/thoracolumbar) of the curves. Real lumbar scoliosis, unbalanced thoracolumbar scoliosis and thoracic and lumbar double curve (lumbar predominant) scoliosis should be properly defined before being compared. Lumbo-sacral scoliosis should be analyzed independently. The lower thresholds of the preventive surgical indications for anterior instrumentation as a means of treating idiopathic scoliosis in lumbar area in adolescents and young adults cannot be defined solely in terms of the Cobb angle. By referring to the three classes of curves listed above, it should be possible to determine the respective advantages and disadvantages of anterior and posterior instrumentation in order to choose the most appropriate strategy in each case.

Conflict of interest M. Bergoin and J.M. Gennari are consultants for EUROS Company and had received honoraria from EUROS. No benefits in any form have been or will be received from a commercial party related directly or indirectly to the subject of this manuscript.

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