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Michael Thomas Muschik
Holger Kimmich
Thomas Demmel

Comparison of anterior and posterior double-rod instrumentation for thoracic idiopathic scoliosis: results of 141 patients

M. T. Muschik (✉)
Orthopädische Abteilung, Park-Klinik
Berlin, Berlin, Germany
E-mail: muschik@park-klinik.com
Tel.: +49-30-96283752
Fax: +49-30-96283755

H. Kimmich · T. Demmel
Klinik für Orthopädie,
Seehospital Sahlenburg, Cuxhaven,
Germany

Abstract Ventral derotation spondylodesis, according to Zielke, achieves good results in operative treatment of idiopathic thoracic scolioses. Corrections of scoliotic major and secondary curve as well as derotation of the spine are reliably performed. The high rate of rod fractures with subsequent correction loss as well as a proportionate kyphogenic effect represents a problem. By keeping to the correcting principle, anterior double-rod instrumentation (Halm-Zielke Instrumentation) is to be stable in a similar way as posterior double-rod systems. Thus, it is done to facilitate brace-free postoperative care and to prevent excessive kyphotic pattern of the spine. In this prospective study, we retrospectively collected data. We performed radiological follow-up of two groups of patients with idiopathic thoracic scoliosis (King II, III and IV) undergoing an operation with posterior approach (USS instrumentation, posterior group, $n = 104$) in 1997 and 1998 or being corrected with an anterior fusion (Halm-Zielke instrumentation, anterior group, $n = 37$) between 2000 and 2001. Mean age of all patients for operation was 15 ± 4 years. Follow-up was performed after 4 ± 2 years on average. Preoperative measurements of the major and secondary curve, the lateral profile, rotation and frontal balance (C7 to S1) did not show any significant differences apart from a more severe scoliotic curve in the lumbar spine for the anterior group with appropriately higher lumbar rotation. During follow-up we noticed similar corrections of the thoracic major and lumbar curve in both groups ranging from 49 to 56%. In case of hypokyphotic (T4–T12 $\leq$ 20°) scoliosis a kyphogenic effect on the thoracic spine was achieved with both surgical methods. Hyperkyphotic (T4–T12$\geq$40°) scolioses were flattened by posterior spinal fusion; the effect of anterior spinal fusion was not significant. Correction of thoracic and lumbar rotation in the anterior group by 37 or 30% was more significant than in the posterior group by 27 or 20%. There was no impact of anterior technique on the balance of the spine whereas the latter shifted by an average of 7 mm to the left in the posterior group. The number of fused segments was significantly smaller in the anterior group with 7 ± 1 vertebral bodies (posterior, 11 ± 1 vertebral bodies). Rates of complication were identical with 11 or 12% in both groups during follow-up. Anterior and posterior double-rod instrumentations result in comparable corrections for idiopathic thoracic scoliosis of the major and secondary curve. In case of posterior technique, however, four vertebral bodies less were integrated in spondylodesis on average. Balance of the spine did not

change after anterior spondylodesis; however, it declined by using the posterior technique. Augmentation of the anterior threaded rod combined with a solid second rod significantly decreases the rate of implant breakages and reliably reduces consecutive correction losses.

Keywords Idiopathic scoliosis · Posterior spondylodesis · Anterior spondylodesis

Introduction

Anterior instrumentation for scoliosis is associated with the names of Dwyer and Zielke [11, 12, 41, 44–46]. Compared to posterior double-rod instrumentation the shorter fusion length that can normally be performed between the neutral end vertebrae of the major curve is an advantage. The essential disadvantage of Zielke instrumentation or other implants using a single threaded rod is inadequate primary stability, thereby making brace-free postoperative treatment insecure. Despite immobilization of the trunk for several months, a breakage rate of the threaded rod up to 43% following correction loss is unavoidable.

In 1999, Betz et al. [4] published a diligently performed prospective multi-center study and compared anterior instrumentation using a single 3.2 mm threaded rod to posterior double-rod instrumentation and fusion of adolescent idiopathic scoliosis. Coronal correction and balance of spine were identical in both operative techniques. By using the anterior approach, an average of 2.5 lumbar segments less could be fused as would have been indicated in case of posterior instrumentations. However, the rate of breakage of the 3.2 mm flexible threaded rod amounting to 31% as well as the correction loss and pseudarthrosis were unacceptably high.

Anterior double-rod systems, such as the Kaneda system [23] or the Cotrel–Dubousset–Hopf Instrumentation [20], reliably prevent rod breakages, but lose the excellent correction principle resulting from the original VDS according to Zielke, that is a drawback in case of severe scoliosis from the authors' point of view. Furthermore, these systems are relatively rigid and thus result in screw breakouts occasionally from cranial or caudal end vertebrae intraoperatively or postoperatively [5, 28].

On the basis of the Zielke instrumentation, Halm developed a system combining advantages of a flexible threaded rod with the stability of a second solid rod. This instrumentation was developed to preserve the efficiency of ventral derotation spondylodesis when a relatively short fusion length corrected scoliosis on the one hand and on the other hand to complete it in such a way that a primary stable instrumentation significantly reduced the rate of breakages and allowed brace-free postoperative care. In addition, kyphogenic effect was to be decreased [8, 14, 16]. In a prospective study comprising 45 patients with idiopathic scoliosis, Bullmann et al. were able to show that a good correction of the scoliotic major curve and the apical rotation were achieved equally by using the Halm-Zielke instrumentation. In only two patients (4%) implant breakages with occurrence of pseudarthrosis were noted during follow-up performed after 2 years on average.

Between 1995 and 1999, operative care of thoracic adolescent idiopathic scoliosis was done by the senior author performing posterior spondylodesis using the Universal Spinal System (Synthes) (Fig. 1a–d). When we introduced the Halm-Zielke instrumentation (DePuy) in our hospital in 1999 there was a change in the method of treatment. From then on adolescent idiopathic thoracic scolioses were operated on by anterior spondylodesis (Fig. 2a–d). The present study aimed at comparing results of our posterior and anterior instrumentation and double-rod fusion.

Patients and methods

To minimize the effects of "learning curves", two groups of patients both for posterior approach (1997 and 1998) and anterior approach (2000 and 2001) were selected and all patients were followed-up retrospectively in our polyclinic department. Patients operated on with combined anterior/posterior approaches were excluded from this study. A total of 141 patients with idiopathic thoracic scoliosis King type II, III and IV (104 posterior instrumentations and fusions and 37 anterior instrumentations and fusions) met the required criteria for inclusion.

Operative surgery was indicated in both groups with a thoracic major curve Cobb greater than or equal to 40°. In 14 patients, we noted a proven progression that averaged $9 \pm 2°$ within 6 months; so operation was already indicated with $38 \pm 2 (35–39)°$.

For posterior instrumentation, selection of vertebrae to be instrumented was done according to the guidelines of Shufflebarger and Clark [40], Webb et al. [43] and King et al. [24]. The "stable vertebra" was the most proximal lower thoracic or upper lumbar vertebra most closely bisected by this vertically oriented center sacral line. In a kyphosis between T4 and T12 below 40°, the cranial end vertebra of instrumentation was the end vertebra of scoliosis; in more severe kyphoses, the instrumentation was the extended cranial. The lower end

Fig. 1 a–d Preoperative and follow-up p.a. and lateral X-rays of a 15-year-old girl with idiopathic adolescent thoracic scoliosis (posterior instrumentation and fusion, T3–L1, Universal spinal system)
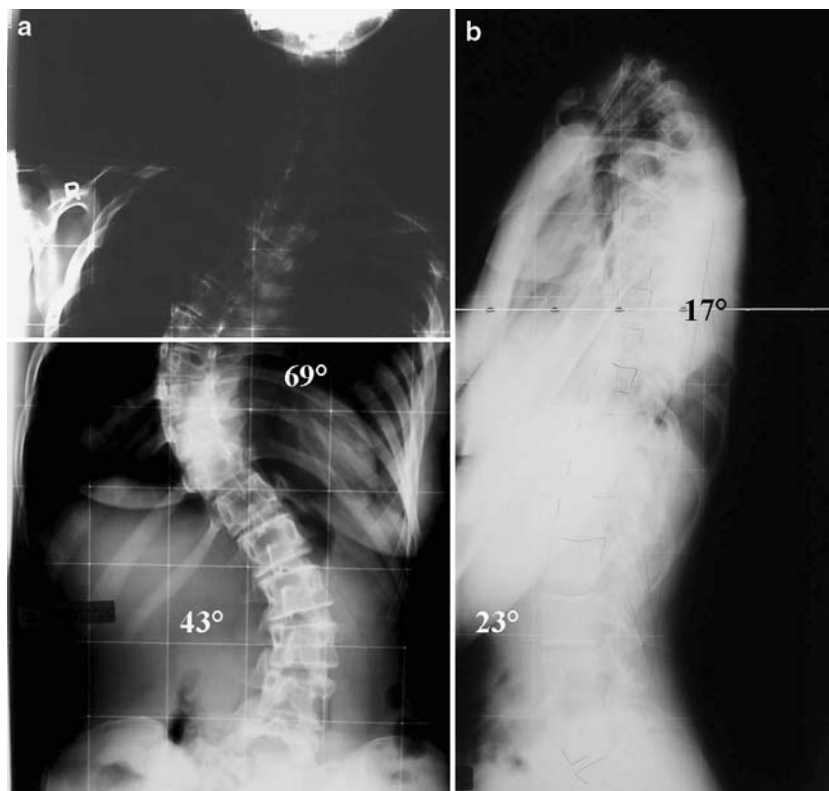
vertebrae were provided with pedicle screws. Iliac crest graft was prepared for spinal fusion [10, 43].

Anterior spinal fusion was done through transthoracic approach up to the 12th thoracic vertebral body and occasionally up to the 1st lumbar vertebral body; for further vertebrae to be instrumented caudally, the transpleural retroperitoneal approach was chosen according to Hodgson [1]. In case of double thoracotomies the third or fourth rib below the rib to be removed cranially was normally chosen. Instrumentation was performed from end to end vertebra of the major curve [16].

Follow-up was brace-free in both groups. We performed radiological follow-ups postoperatively as well as 3, 6, 12 and 24 months after surgery, then in 2-year intervals.

Evaluation of complications was performed on the basis of patients' documents and X-rays. The magnitude of the major and secondary curve (Cobb angle) as well as rotation of the apical vertebra of the major and secondary curve, according to Perdriolle [37], was determined on the basis of posterior–anterior X-rays of the spine. Balance of the spine was determined from spinous process of the seventh cervical vertebra as a distance to the center sacral line after horizontalization. Spines presenting deviations from balance within 1 cm to the left or to the right (−1 cm to +1 cm) were evaluated as balanced, for greater deviations we considered the spine

imbalanced to the right (> +1 cm) or to the left (> −1 cm). We documented extension of instrumentation, implant loosening or breakages as well as pseudarthroses. On lateral radiographs, kyphosis was determined between the 4th and 12th thoracic vertebral body as well as lordosis between the 1st and 5th lumbar vertebral body. Furthermore, we subdivided scolioses on preoperative radiographs according to King classification [24] and determined the Risser sign.

Statistical evaluation was done through the statistical program PS/PC + 4. We calculated the mean and standard deviation, and reported the range (minimum–maximum). Normal distribution of the database was not always likely. We, therefore, used nonparametric tests (Wilcoxon test, 95% confidence interval).

Results

Age for operation was significantly lower with 14 ± 2 (10–22) years in the posterior group than in the anterior group with 17 ± 3 (11–29) years ($P = 0.00$). In the posterior group we noted 16 boys and 88 girls, in the anterior group 5 boys and 32 girls. Follow-up was performed after 4 ± 1 (2–7) years in the posterior group and after 3 ± 1 (2–3) years in the anterior group ($P = 0.00$). In the anterior group, we noticed 19 scoliotic curves type II

Fig. 1 (Contd.)
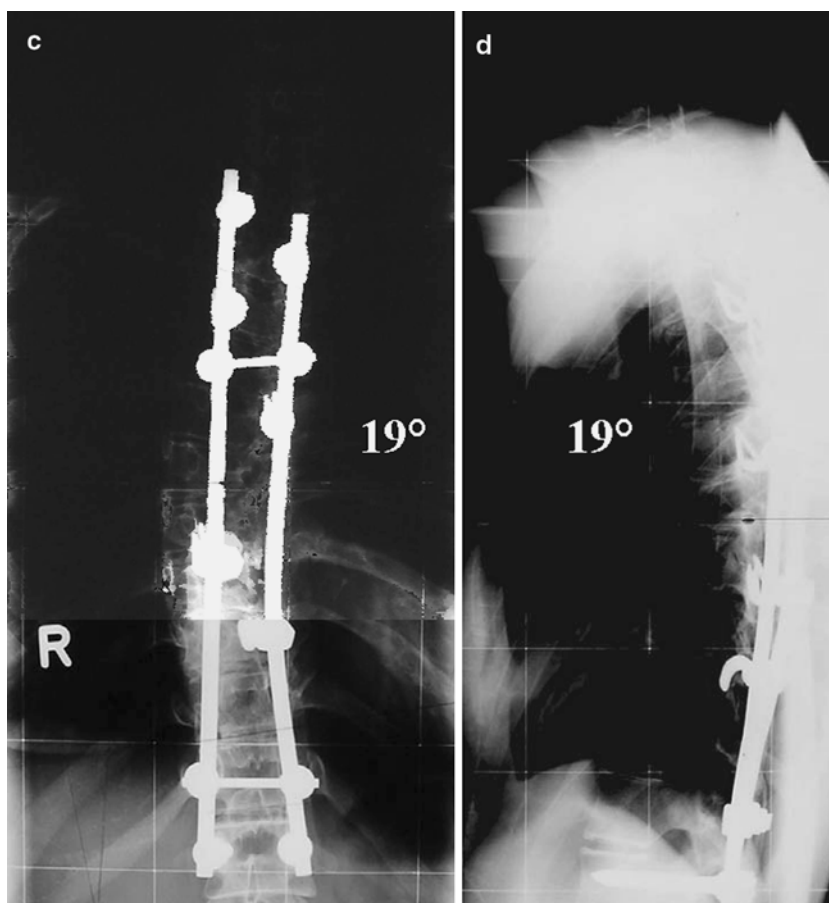
according to King's classification, 14 curves of type III and 4 curves of type IV (posterior group 68, 23 and 13 scoliotic curves accordingly).

Only 7 patients showed a Risser stage 0 and 1 pre-operatively (2 patients of the anterior and 5 patients of the posterior group), whereas 134 patients showed Risser 2 and more.

Operative intervention lasted 3.6 ± 1.1 (2–6) h for the anterior group and 3.8 ± 1.0 (3–5) h ($P < 0.05$) for the posterior group. Using the anterior approach, patients lost $1,662 \pm 707$ (300–3,100) ml of blood on average, using the posterior approach $1,864 \pm 524$ (1,100–2,400) ml ($P < 0.01$).

The radiographic analyses of preoperative, postoperative and follow-up measurements are summarized in Table 1. Preoperatively, lumbar secondary curvature and lumbar rotation showed a higher magnitude in the anterior group, however, values of the thoracic curve as well as lateral profile and balance did not differ between both groups. For follow-up, we noted significant corrections of thoracic major and lumbar secondary curve in both groups as well as of thoracic and lumbar rotation. On average, thoracic kyphosis was affected neither by anterior nor by posterior approach.

If the magnitude of corrections is analyzed more precisely and compared between both the groups (Table 2), improved corrections will result for the thoracic major curve by posterior spinal fusion, whereas lumbar curves seem to show a better correction after anterior spinal fusion combined with a higher derotation in the lumbar spine as well.

Correction losses in both patient groups hence amounted to an average of 2° at the highest for scoliotic major and secondary curve. Five patients with posterior spinal fusion (4%) showed a correction loss equal to or greater than 10° in the thoracic major curve. Because of a delayed infection, a removal of implant was performed in five patients as well as a new instrumentation and spinal fusion of scoliosis in three of them. In the anterior patient group, we only noted correction loss by 10° in one female patient (3%).

A more precise analysis of thoracic kyphosis prior to and after operative treatment is represented in Table. 3 and 4. Thus, we observed a total of 61 patients in both groups presenting significant lordoscoliosis (Table 3), i.e. thoracic kyphosis was $\leq 20°$. Using both surgical techniques, a kyphogenic effect could be demonstrated which, however, is of greater significance with the

Fig. 2 a–d Preoperative and follow-up p.a. and lateral X-rays of a 16-year-old girl with idiopathic adolescent thoracic scoliosis (anterior instrumentation and fusion, T5–T12, Halm-Zielke system)
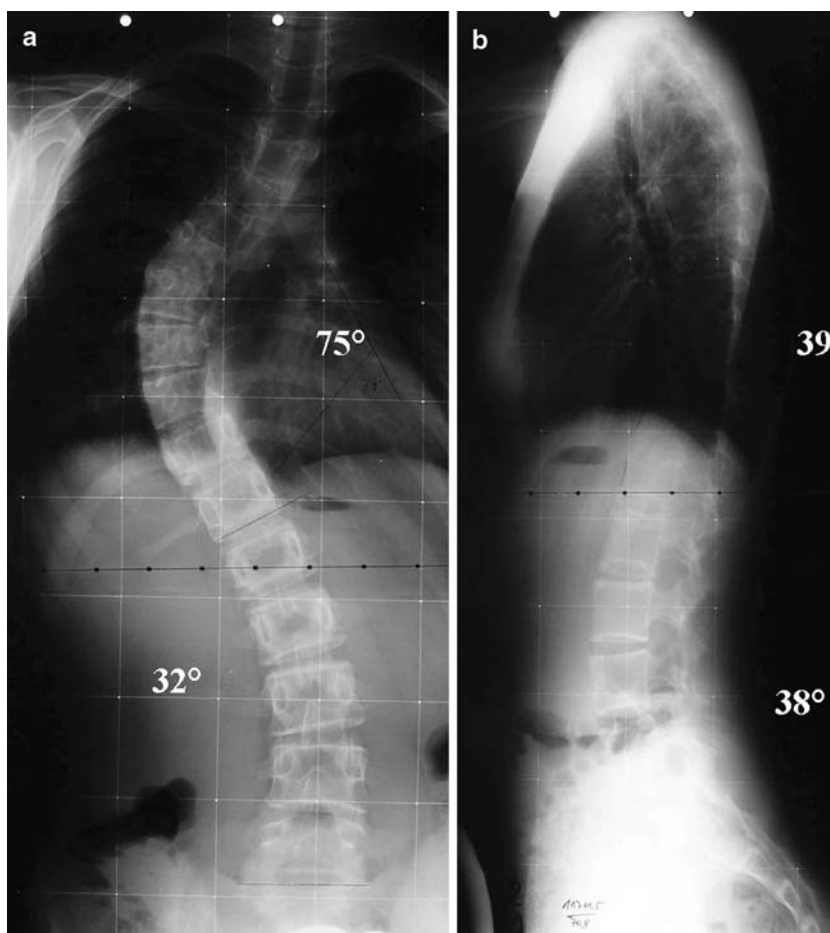
anterior approach. However, a significant lordotic effect for kyphoscolioses, i.e. in patients with preoperative kyphosis equal to or greater than 40° (Table 4) could only be guaranteed in the posterior group. There was no difference in the anterior group.

Balance of the spine was not affected by anterior spinal fusion (Table 1). On the other hand balance considerably declined after posterior fusions. In this case, imbalance of the spine was increased to the left from −0.2 to −0.9 cm on average for all patients. In addition, during follow-up, we also noticed a shift of spines imbalanced to the left (from 38 to 62%) by simultaneous reduction of the part of balanced spines (from 50 to 32%) in patients with posterior approach (Table 5).

The number of vertebrae included in spinal fusion at the lowest level of instrumentation led to different frequencies (Table 6) in both patient groups. In the anterior group, instrumentation ended distally between T10 and L1 in 32 out of 37 patients (86%), but in the posterior group in only 50 out of 104 patients (48%, $P < 0.001$). In anterior spinal fusions, an average of 7 ± 1 (4–8) vertebrae were fused while in posterior spinal fusions 11 ± 1 (8–14) vertebrae ($P < 0.01$) were fused.

Observed complications are summarized in Table 7. Neurological complications did not occur in any of both groups; in the same way, healing by first intention was always without disturbance.

In the group of posterior spinal fusions, delayed infections (12, 13, 13, 15 and 18 months postoperatively) occurred in five patients through occurrence of fistula formation. Preoperative and intraoperative microbiological examinations did not produce any bacterial detection, but cultivation amounted to a maximum of 3 days. After complete implant removal (and new instrumentation in three patients), wounds healed without complications. A cast syndrome could be treated conservatively. In two patients, an increase in non-instrumented lumbar curvature occurred which required extension of spinal fusion caudally. Intraoperatively, a pseudathrosis occurred in one patient that was resected and filled with autologous bone graft. Screw breakage with a further pseudarthrosis required revision including replacement of screw and autologous grafting.

Fig. 2 (Contd.)
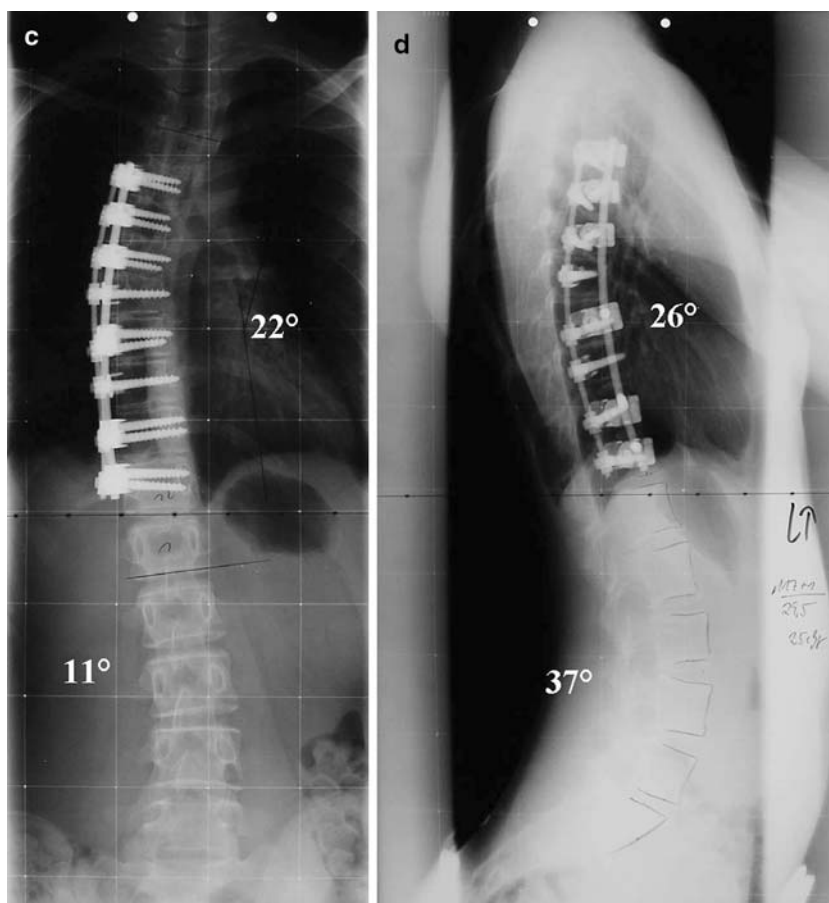
In the anterior spinal fusion group, a screw pullout already occurred in two patients at the cranial end of instrumentation (each at T6) intraoperatively. In this case, spinal fusion was extended by a segment above. At 12-month control, we noted a breakage and caudal dislocation of threaded rod, in another patient, multiple breakages of the threaded rod and the rigid rod. Based on radiographs, this probably resulted from a formation of pseudarthrosis in these two patients.

On the whole, complication rate was equal in both procedures with 11 or 12%, but reoperation frequency was significantly higher in posterior spinal fusions (eight reoperations vs. no operative revision in anterior fusions).

Discussion

It is an indisputable disadvantage of this study that patients were not randomized. Patient groups in the study differed not only in size but also in age and follow-up time; both factors may be related to the outcome.

Patients were operated upon by the senior author at two different institutions (posterior spondylodesis at Charité hospital, Berlin and anterior spondylodesis at Seehospital Sahlenburg, Cuxhaven). Because of the high rate of metal breakages of the Zielke-VDS, the more stable posterior spinal fusion was the standard for treating idiopathic thoracic scoliosis at Charité hospital. At Seehospital Sahlenburg, where the author has worked for 5 years between 1999 and 2004, this therapeutical concept was changed in favor of anterior double-rod instrumentation.

By selective anterior instrumentation and fusion, a good correction of thoracic major and lumbar non-instrumented secondary curve was achieved. This surgical technique constitutes an advantage with respect to a shorter fusion length, good derotation and sufficient correction of lumbar secondary curve. But the instrumentation developed by Zielke including a thin threaded rod or similar anterior systems including single flexible threaded rods do not achieve primary stability. This lack of stability leads to a high rate of implant fractures, pseudarthroses and subsequent correction losses. Consequently, rod fractures ranging from 2 to 43%, rates of pseudarthrosis of 5–23% and correction losses between 6° and 12° are indicated by many authors [4, 21, 30, 33, 35, 38]. In addition, a kyphotic effect occurs by

Table 1 Comparison between preoperative, postoperative and follow-up results of measurements of thoracic major, lumbar secondary curve, thoracic and lumbar rotation in the apex of curvature as well as thoracic kyphosis, lumbar lordosis and balance between anterior and posterior spinal fusion

	Anterior spondylodesis	Posterior spondylodesis	Significance
Preoperative			
Thoracic Cobb angle	51 ± 11 (36–89)	54 ± 11 (38–95)	0.11 (NS)
Lumbar Cobb angle	43 ± 17 (11–77)	34 ± 11 (11–75)	0.00
Thoracic kyphosis	24 ± 13 (2–52)	21 ± 14 (−13–61)	0.10 (NS)
Lumbar lordosis	46 ± 12 (26–77)	47 ± 12 (22–83)	0.48 (NS)
Thoracic rotation	19 ± 12 (0–40)	22 ± 8 (5–35)	0.06 (NS)
Lumbar rotation	20 ± 15 (0–50)	10 ± 8 (0–40)	0.00
Balance (in cm)	−0.7 ± 1.9 (−5–3)	−0.2 ± 1.4 (−4–4)	0.07 (NS)
Postoperative			
Thoracic Cobb angle	23 ± 12 (7–60)*	23 ± 9 (8–49)*	0.42 (NS)
Lumbar Cobb angle	19 ± 14 (1–66)*	14 ± 7 (4–39)*	0.01
Thoracic kyphosis	25 ± 13 (3–60)[NS preop]	21 ± 9 (5–41)[NS preop]	0.01
Lumbar lordosis	39 ± 13 (15–75)*	43 ± 11 (22–57)*	0.00
Thoracic rotation	13 ± 9 (0–30)*	18 ± 10 (0–40)*	0.00
Lumbar rotation	13 ± 10 (0–45)*	9 ± 8 (0–40)*	0.00
Balance (in cm)	−0.5 ± 1.8 (−3–32)*	−0.9 ± 1.1 (−5–2)*	0.02
Follow-up			
Thoracic Cobb angle	25 ± 12 (4–58)*, **	24 ± 9 (7–55) *, **	0.24 (NS)
Lumbar Cobb angle	21 ± 14 (2–63)*, **	16 ± 8 (5–47)*, **	0.00
Thoracic kyphosis	27 ± 13 (2–47)[NS preop, NS postop]	22 ± 11 (5–79)[NS preop, NS postop]	0.02
Lumbar lordosis	44 ± 12 (19–71)*, **	45 ± 12 (20–65)*, **	0.48 (NS)
Thoracic rotation	12 ± 8 (0–30)*, **	16 ± 9 (0–40)*, **	0.03
Lumbar rotation	14 ± 10 (0–45)*, **	8 ± 6 (0–25)*, **	0.00
Balance (in cm)	−0.4 ± 1.6 (−4–3)[NS preop NS postop]	−0.9 ± 1.1 (−5–2)*, **	0.04

Values in ° (degrees)

Mean ± standard deviation and range (minimum–maximum)

Balance: − spine imbalanced to the left, + spine imbalanced to the right

NS preop not significant compared to preoperative value, *NS postop* not significant compared to postoperative value

*$P < 0.05$ compared to preoperative value

**$P < 0.05$ compared to postoperative value

shortening and compressing the anterior spine which cannot be desirable in lumbar and already preoperatively hyperkyphotic thoracic scoliosis [21, 30, 34, 35].

Frontal plane correction

We have hence achieved a mean correction of instrumented thoracic scoliosis from 51° to 25° using the Halm-Zielke instrumentation. A significant correction loss of an average of 2° was proved between immediate postoperative measurement and follow-up; a long-term correction of 51% was consequently achieved. Bullmann et al. [8] published similar values in their prospective study comprising 64 patients with idiopathic thoracic scoliosis.

In addition, this correlates well with the correction magnitude of 58% for thoracic curve mentioned by Betz

Table 2 Corrections (differences of preoperative measurements compared to follow-up) of thoracic major and lumbar secondary curve, of thoracic and lumbar rotation in the apex of the curve as well as of thoracic kyphosis, of lumbar lordosis and balance for patients with anterior or posterior spinal fusions

	Anterior spondylodesis	Posterior spondylodesis	Significance
Thoracic Cobb angle	26 ± 13 (3–51)	31 ± 10 (2–67)	0.02
Lumbar Cobb angle	22 ± 12 (5–59)	17 ± 13 (−11–58)	0.04
Thoracic kyphosis	−2 ± 13 (−31–29)	−1 ± 12 (−31–47)	0.32 (NS)
Lumbar lordosis	2 ± 12 (−25–30)	2 ± 13 (−30–30)	0.50 (NS)
Thoracic rotation	7 ± 8 (−5–30)	6 ± 7 (−5–25)	0.40 (NS)
Lumbar rotation	6 ± 11 (−5–45)	3 ± 7 (−10–30)	0.02
Balance (in cm)	−0.3 ± 1.3 (−3.4–2.8)	0.6 ± 1.7 (−3.0–6.5)	0.00

Values in ° (degrees)

Mean ± standard deviation and range (minimum–maximum)

Balance: − spine imbalanced to the left, + spine imbalanced to the right

NS not significant

Table 3 Comparison of change of thoracic kyphosis T4–T12 preoperative, postoperative and follow-up (only patients with lordoscolioses, i.e. presenting a thoracic hypokyphosis T4–T12 ≤ 20°) with anterior versus posterior spinal fusions

Lordoscolioses (kyphosis T4–T12 ≤ 20°)	Anterior spondylodesis ($n = 13$)	Posterior spondylodesis ($n = 48$)	Significance
Preoperative	11 ± 5 (2–19)	11 ± 7 (−13–20)	NS
Postoperative	22 ± 16 (3–60)*	17 ± 8 (5–38)*	< 0.01
Follow-up	21 ± 12 (2–44)*, NS	17 ± 7 (5–30)*, NS	< 0.01

Values in ° (degrees)

Mean ± standard deviation and range (minimum–maximum)

*$P < 0.05$ compared to preoperative value

NS not significant compared to postoperative value

et al [4]. by using a single flexible threaded rod. Also, many other authors report similar values for frontal plane correction both for Zielke instrumentation [21, 22, 30, 33, 38, 45, 46] and for rigid anterior systems ranging from 46 to 90% [2–4, 19, 23, 26, 29, 32, 42]. In case of rigid anterior instrumentation, correction loss between 1.5° and 6° is reported [2, 20, 23, 32, 42]; we, therefore, judge that our operative outcomes can be realistically achieved.

Non-instrumented lumbar scoliosis presented a mean correction from 43° to 21°. This also correlates well with lumbar correction mentioned by Bullmann et al. for Halm-Zielke instrumentation. Lenke et al. have reported about 56% of spontaneous correction of lumbar spine in 123 patients with a 2-year follow-up after selective thoracic correction by using a single threaded rod.

There is a slight increase in correction of the thoracic major curve in our study in the posterior group with 55% versus the anterior group with 51% ($P = 0.02$). Betz et al. noticed similar corrections ranging from 58 or 59% ($P = 0.92$) when comparing between 78 patients with anterior and 100 patients with posterior instrumentation.

In our study, lumbar curve was corrected after anterior instrumentation by 51%, after posterior instrumentation by 53% ($P = 0.04$). On the whole, corrections of coronal major and secondary curve to be achieved by anterior or posterior double-rod instrumentation seem to differ only slightly and are of no clinical importance.

Whether the lower number of vertebrae integrated in spinal fusion presents a clinical advantage for patients in case of selective anterior instrumentation cannot be answered through this study. No study is known to us that could document different clinical outcomes depending on the fusion level in patients with idiopathic thoracic scoliosis.

In our study we have fused an average of 7 vertebrae anterior versus 11 vertebrae posterior. In 1985, Hammerberg and Zielke [17] had already reported that a mean saving in 2.3 distal segments was achieved according to a study of 32 VDS patients. Betz et al. have proved that an average of 2.5 distal segments could be spared and considered this as the significant result of their study. This group of authors could limit 97% of anterior fusions to the distal segments T10 up to L1; in our study, the rate was 86%. In contrast, in posterior fusions of our study, only 48% were instrumented distally up to L1; the same in the case of Betz et al. [4] was only 18%. It is possible that this difference results from the fact that we always used pedicle screws in the lumbar section in our patients; however, Betz et al. had used Cotrel-Dubousset or Texas Scottish Rite Hospital hook-rod instrumentation.

Derotation

Analysis of measurements for derotation of thoracic spine confirmed good correction both with the anterior and posterior procedures. Halm-Zielke instrumentation achieved 37% derotation and the posterior approach 27% ($P = 0.40$).

The magnitude of thoracic derotation determined in our study for anterior instrumentation is situated in the lower range of values determined by other authors. Thus, rotational corrections ranging from 37 to 51% are indicated for VDS, according to Zielke; for the Halm-Zielke instrumentation Bullmann et al. determined 52% of apical derotation.

In contrast, degrees of correction achieved by the CD maneuver for derotation of the scoliotic spine were disputed for a long time. Performing measurements

Table 4 Comparison of change of thoracic kyphosis T4–T12 preoperative, postoperative and follow-up (only patients with kyphoscolioses, i.e. presenting a thoracic hyperkyphosis T4–T12≥40°) with anterior versus posterior spinal fusions

Kyphoscolioses (kyphosis T4–T12≥40°)	Anterior spondylodesis ($n = 3$)	Posterior spondylodesis ($n = 9$)	Significance
Preoperative	48 ± 5 (42, 49, 52)	48 ± 8 (40–61)	NS
Postoperative	34 ± 10 (23, 36, 42)[a]	29 ± 9 (18–41)$^{P < 0.05}$	NS
Follow-up	35 ± 12 (23, 35, 47)[a, b]	29 ± 13 (14–50)$^{P < 0.05, b}$	NS

Values in ° (degrees)

Mean ± standard deviation and (detailed data) for anterior spondylodesis

Mean ± standard deviation and range (minimum–maximum) for posterior spondylodesis

NS not significant

$P < 0.05$ compared to preoperative value

[a] Not significant compared to preoperative value

[b] Not significant compared to postoperative value

Table 5 Number of patients (absolute and percent) whose spine is balanced (distance of sacrum midline to balance from spinous process C7 ≤ 1 cm) or imbalanced to the right or to the left (distance of sacrum midline to balance from spinous process C7 > 1 cm) preoperatively and for date of follow-up separately for anterior and posterior spinal fusions

	Anterior spondylodesis			Posterior spondylodesis		
	Imbalanced to the left	Balanced	Imbalanced to the right	Imbalanced to the left	Balanced	Imbalanced to the right
Preoperative	17 (46%)	12 (32%)	8 (22%)	40 (38%)	52 (50%)	12 (12%)
Follow-up	14 (38%)	15 (40%)	8 (22%)	64 (62%)	33 (32%)	7 (7%)

according to the Perdriolle method [39], Schlenzka et al. did not observe any significant improvement of thoracic rotation in the retrospective analysis of 52 patients in their CD group. Neither could Krismer et al. [25] nor Lenke et al. [27] document a correction of rotation by using computer-tomographic determinations. By contrast, there are analyses on radiographs and in CT in which a derotation of scoliosis between 20 to 40% of the initial value is described postoperatively [13, 18, 37]. Results of our study emphasize the possibility of achieving and preserving a derotation of the thoracic major curve by using posterior double-rod instrumentation. In our opinion, statistically significant derotation results from application of pedicle screws at the caudal end of instrumentation. We hereby suppose a force addressing the spine closer to the rotation center as in lamina hooks addressing the spine further posterior.

Sagittal profile

Measurements of sagittal profile must always be interpreted critically because two basic problems, as was the case in our study, had not been considered when thoracic kyphosis was measured in idiopathic scoliosis.

First, we had always measured kyphosis between T4 and T12. We did not consider that idiopathic scoliosis had a lordotic effect at the apex of the curve. Constant measurements of kyphosis between T4 and T12 may

level these differences. The second problem arises when preoperative and postoperative lateral standing radiographs may no longer allow a guaranteed comparison caused by intraoperative derotation. Production of "true lateral" projections should be required in this case, i.e., exposure in oblique projection, according to respective apex rotation.

Thoracic kyphosis did not show any differences in the mean value of all patients both between either of the therapy groups and between preoperative and postoperative measurements. Both surgical methods had no effect on the lateral profile on average. Especially, it was not anymore required to prove the kyphogenic effect of Zielke instrumentation [21, 33, 38].

Thus, Betz et al., for example, determined a postoperative hyperkyphosis of more than 40° in 40% of their patients who had undergone anterior approach if thoracic kyphosis was already greater than 20° preoperatively.

If preoperative lordoscolioses or kyphoscolioses are considered separately in our study (Table. 3, 4) and if impact of both surgical techniques is analyzed separately, it will result in a more distinct view.

As to lordoscolioses, flat-back syndrome could permanently be prevented. As expected, a more significant kyphotic effect in the anterior group was achieved (22° vs. 17°, $P < 0.01$). Consequently lordoscolioses are very probably adjusted to a physiologic range between 20° and 40° by anterior double-rod instrumentation [6].

Table 6 Number of the most caudally instrumented vertebrae separately for anterior and posterior spinal fusions

	Anterior spondylodesis	Posterior spondylodesis
T10	7	
T11	13	4
T12	7	13
L1	5	33
L2	3	28
L3	2	23
L4		3[a]

[a]Including two patients with secondary extension of spinal fusion up to L4 after lumbar decompensation

Table 7 Complications of anterior and posterior spondylodesis

	Anterior spondylodesis	Posterior spondylodesis
Late infection		5[a]
Lumbar decompression		2[a]
Hook dislodgement		1
Intraoperative screw pullout	2	2
Cast syndrome		1
Pseudarthrosis in case of metal breakage	2	1[a]
	4 (11%)	12 (10%)

[a]Operative revision was performed

Even in preoperative hyperkyphotic scoliosis, no tendency to augment kyphosis using anterior double-rod instrumentation was noted with the reservation that only three patients showed thoracic hyperkyphosis greater than 40° between T4 and T12 preoperatively.

Coronal balance

In our study a positive impact of anterior procedure was observed on the balance of the spine [4, 26, 38]. While there was no significant difference between both patient groups preoperatively, we noticed at follow-up that balance after anterior instrumentation was not affected whereas after posterior instrumentation, it shifted by an average of 0.7 cm to the left. All in all, we did not get the impression, however, that changes of balance were of clinical importance to our patients. Balance problems of the spine were described in connection with CD procedure. There would, especially, be a risk for scoliosis showing a deviation from the midline preoperatively (C7 to S1) and for which instrumentation was only extended to the "stable" vertebra that corresponds to our approach [7].

Crankshaft

We have not observed any crankshaft phenomenon in seven patients operated on in Risser stage 0 and 1. A more precise analysis did not seem useful to us because of the low number of cases. In addition, accuracy of measurement of rotation according to Perdriolle's method is limited. We also assess the follow-up period to be too short to make statements that would be valid beyond case history. For similar reasons, Betz et al. [4] also refrained from an analysis of crankshaft problems.

Complications

Although material breakages occurred in our series also in two patients (5%) after anterior double-rod instrumentations, this rate is significantly lower than the rate that was found after application of a single threaded rod [4, 44–46]. Bullmann et al. [9] report a similar low number of two material breakages in their series of 45 patients using Halm-Zielke instrumentation (4%), however, they only occurred in the threaded rods and screws. Breakage of the solid rod [15] by using anterior double-rod system is a unique procedure to date. Our patient is a 17-year-old boy weighing 124 kg who smokes ten cigarettes a day.

To date, none of our patients in the anterior group had to be reoperated. This is a clear improvement versus the reoperation frequency of 10% that Betz et al.described using single threaded rods. In this case, we also see an advantage versus our patients operated on with the posterior approach; the eight reoperations (8%) occurred because of lumbar decompensation, late infections and material-related complications.

Conclusion

In idiopathic scoliosis using anterior double-rod instrumentation, selective thoracic instrumentation results in approximately comparable corrections like posterior double-rod instrumentations. Without being able to prove a clinical improvement in our patients maintaining mobile lumbar segments by using anterior technique seems advantageous to us. Hyperkyphoses frequently observed by using single threaded rod systems may be avoided by using an anterior double-rod system. Anterior and posterior double-rod instrumentations present a comparable rate of complications; however, reoperation rate in our patients is clearly higher by using the posterior technique.

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