Eur Spine J (2002) 11 : 107–114
DOI 10.1007/s00586-001-0356-8

ORIGINAL ARTICLE

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Three-stage surgery in the management of severe rigid angular kyphosis

Received: 17 January 2001
Revised: 29 May 2001
Accepted: 21 September 2001
Published online: 19 October 2001

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Abstract There are conflicting data regarding the management of rigid kyphosis. None of the currently known techniques can completely correct severe kyphosis without resulting in residual deformity. Seven patients with local kyphosis exceeding 60° were operated on to achieve complete correction of the deformity. The surgery consisted of total spondylectomy of the deformed vertebra and simultaneous application of compression–distraction forces to this area. The operation included three stages: The initial stage includes resection of posterior spinal elements and temporary fixation. In the second stage, an anterior corpectomy is performed to conclude the resection, and simultaneous antero-posterior correction is obtained. The final stage includes another posterior procedure to achieve a precise correction and to correct any compensatory curves. All patients were operated on using this technique in a single session. The mean preoperative and postoperative kyphosis angles were 76.1° (range, 65°–92°) and 6° (range, 0°–13°), respectively. Complete bony fusion was achieved after a mean follow-up period of 38 months (range, 26–52 months) without any neurological sequelae or significant loss of correction.

Keywords Kyphosis · Correction · Vertebrectomy · Three-stage surgery

Introduction

Severe angular kyphosis is commonly caused by vertebral destruction following a fracture, an infectious episode or by congenital abnormalities with localized bony malformation. These deformities result in mechanical problems caused by imbalance in the sagittal plane that lead to late neurological sequelae. The risk is substantially increased in the thoracic and thoracolumbar regions. Surgical correction of severe angular kyphosis is crucial in order to prevent these complications.

Various surgical techniques have been described for the correction of kyphotic deformities. Some of them attempt to solve the problem by posterior wedge osteotomies [3, 8, 9, 11, 14, 15, 16, 18], while others have preferred combined procedures [2, 5, 6, 7, 10, 13]. Favourable results have been attained by all these techniques for the correction of deformities not exceeding 50°–60°. However, patients who present with a kyphosis angle of about 90°–100° are left with a residual kyphotic deformity following surgical treatment by these procedures.

Local kyphosis of more than 60° can only be corrected by total spondylectomy of the deformed vertebra and compression–distraction forces applied to this area. It is technically demanding to combine all three stages in a single surgical intervention. A three-stage operation consisting of initial and final posterior procedures and a corrective antero-posterior procedure at a single session may therefore provide a logical alternative. The initial stage consists of posterior vertebrectomy and temporary fixation. The second stage involves an anterior corpectomy to conclude the resection and achieve simultaneous correction. This is followed by the final stage, which includes another posterior procedure to attain a precise correction and correct any compensatory curves.

Table 1 Clinical data of the patients

Case	Age (years)	Aetiology	Kyphosis (°)		Correction		Loss of correction (°)	Follow-up (months)
			Pre-operative	Post-operative	(°)	(%)		
1	40	Congenital	76	5	71	93	3	33
2	35	Congenital	75	6	69	92	4	40
3	28	Post-infection	72	5	67	93	1	48
4	32	Post-infection	68	8	60	88	2	26
5	20	Congenital	85	5	80	94	3	28
6	16	Congenital	92	13	79	85	4	52
7	24	Post-infection	65	0	65	100	0	39
Average	27.8		76.1	6	70.1	92.1	2.4	38

Harms and Böhm were the first investigators the define a surgical technique consisting of three stages [1, 4]. This correction technique included an initial posterior decompression and partial correction, followed by an anterior decompression and correction and completed by an additional correction and establishment of a posterior tension band effect [1, 17]. However, their series included patients with a kyphotic deformity angle ranging between 20° and 48°, and a correction procedure was not performed simultaneously during the operation.

In this study, we present our experience with three-stage surgery, which provides a true correction for the treatment of severe, rigid, angular kyphosis of the thoracolumbar spine.

Materials and methods

Seven patients with severe, angular kyphosis were operated on between January 1996 and September 1998 at our clinic. Four of the patients were men and three were women, with a median age of 28 years (16–40) (Table 1).

Four patients had a congenital and three had a post-infectious aetiology. The latter group consisted of those with a kyphotic deformity who had previously been treated conservatively because of tuberculous spondylitis. There was no evidence of an active infection at the time of surgery (Figs. 1, 2, 3).

All patients complained of serious pain and deformity in their back, but none of them had any neurological symptoms. There was no flexibility of the deformed region on dynamic examinations.

The preoperative and postoperative kyphosis and/or lordosis was determined by measuring angles between the perpendicular lines to the superior endplate above the deformity and to the inferior endplate below the deformity. The correction angle was calculated from the differences.

The resection level was localized at L1–L2 in two patients, at T12–L1 in two patients, at T11 in two patients and at L2–L3 in one patient.

The spinal instrument used for posterior fixation was the Synergy system in three patients and the Moss Miami system in four patients. Harms' cages were inserted as an anterior column support in all patients.

All patients were evaluated using the intra-operative wake-up test for neurological compromise.

All patients were evaluated preoperatively for pain, functional status and appearance of the deformity by the Likert scoring system [9]. Statistical comparisons between preoperative and postoperative scores were performed using the Wilcoxon signed-rank analysis.

Surgical technique

In the first stage, the patient is placed in a prone position on the operating table. The segments to be fused are prepared such that their posterior elements, including the tips of the transverse processes, are exposed. Transpedicular screws are inserted into the upper and lower adjacent vertebrae of the resected segment. The pedicles and laminae of the apical vertebra(e) are resected. Rods are placed on the screws that were previously bent to adapt to the kyphotic deformity in order to achieve transient stability. Compression is not recommended at this stage due to the rigidity of the deformity. Anatomic layers are temporarily closed.

In the second stage, the patient is placed in a lateral decubitus position and the corpus of the apical vertebra(e) is/are exposed through an anterior thoracal or thoracolumbar approach. The spondylectomy is completed by corpectomy of the apical vertebra(e). Following discectomy of the adjacent upper and lower intervertebral spaces, they are filled with autologous spongy bone chips. The posterior operation field is re-exposed and the rods are partially compressed. The spinal column is anteriorly distracted with a spreader while the rods are forced into the opposite direction of the deformity using in situ benders. Partial correction is achieved through this manoeuvre and the rods are accordingly recompressed. These consequent corrective manipulations are repeated until total correction is achieved. The rods must have become straight when the endplates of the vertebral bodies of the adjacent vertebrae are parallel to each other. A Harms' cage filled with autogenous bone is prepared to fit the anterior gap and inserted while the extension effect is maintained by in situ benders posteriorly. The benders are released and the cage is locked between the two vertebral bodies. The procedure is completed and the layers are closed *per primum intentionem*.

In the third stage, the patient is placed in the prone position again so that the posterior correction and instrumentation can be completed and the posterior tension band effect is established. All the segments to be fused proximally and distally are provided with transpedicular screws. Rods that had previously bent to adapt to the physiological sagittal contours are consecutively replaced with the transient fixation rods. The compensatory lordotic segments proximal and distal to the apical vertebra(e) are distracted. This distraction diminishes the lumbar lordosis. Translation screws have to be used in the thoracal region, as a result of which posterior translation and further correction of the thoracic lordosis can be obtained. The kyphotic area is compressed bilaterally, and the correction in this segment is also completed. The translation

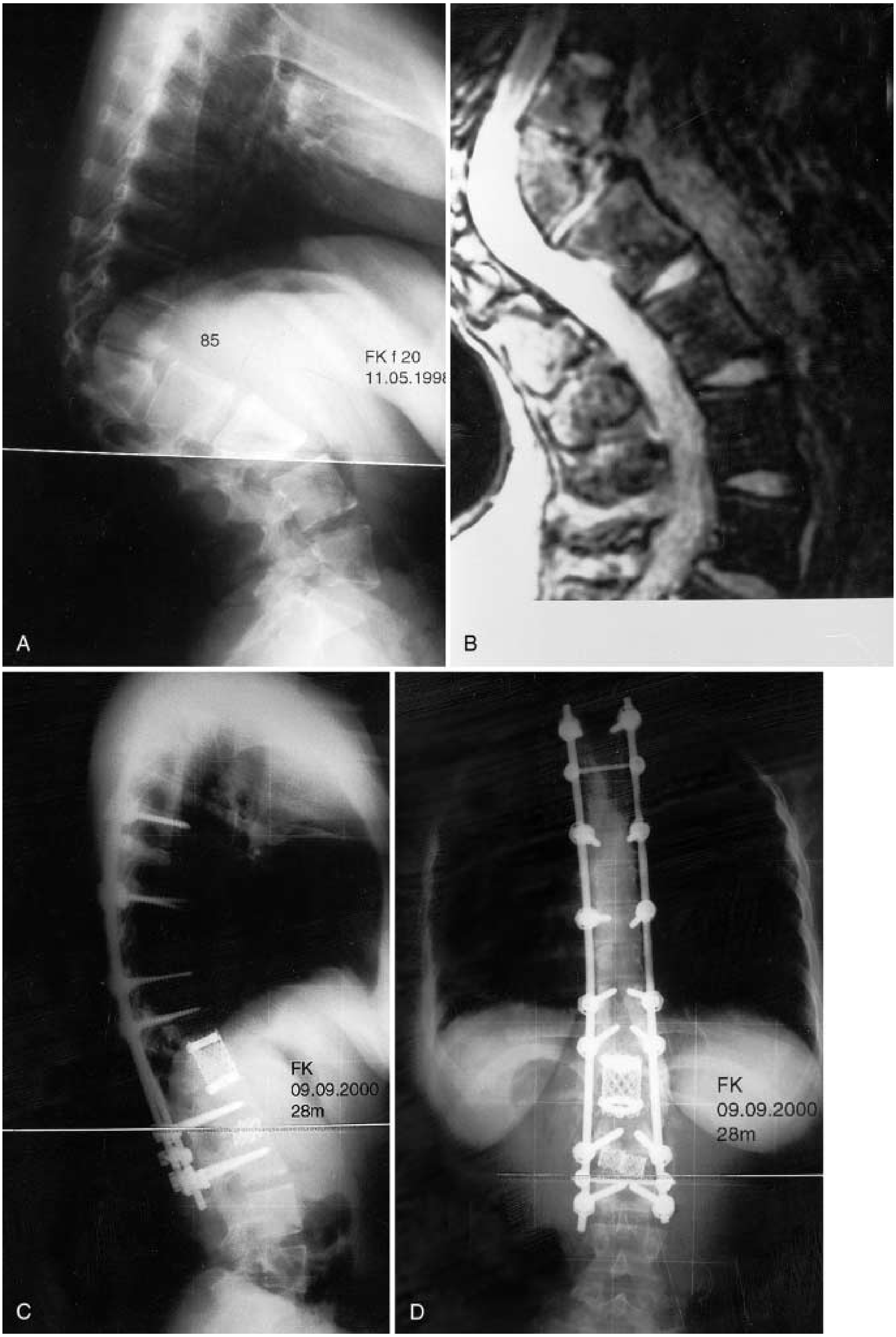

Fig. 1 **a** Preoperative lateral X-ray of patient no. 5 with an 85° kyphosis. **b** Preoperative magnetic resonance imaging (MRI) of the same patient in the sagittal plane. **c,d** Postoperative X-rays at the end of the 28th month with 5° residual kyphosis

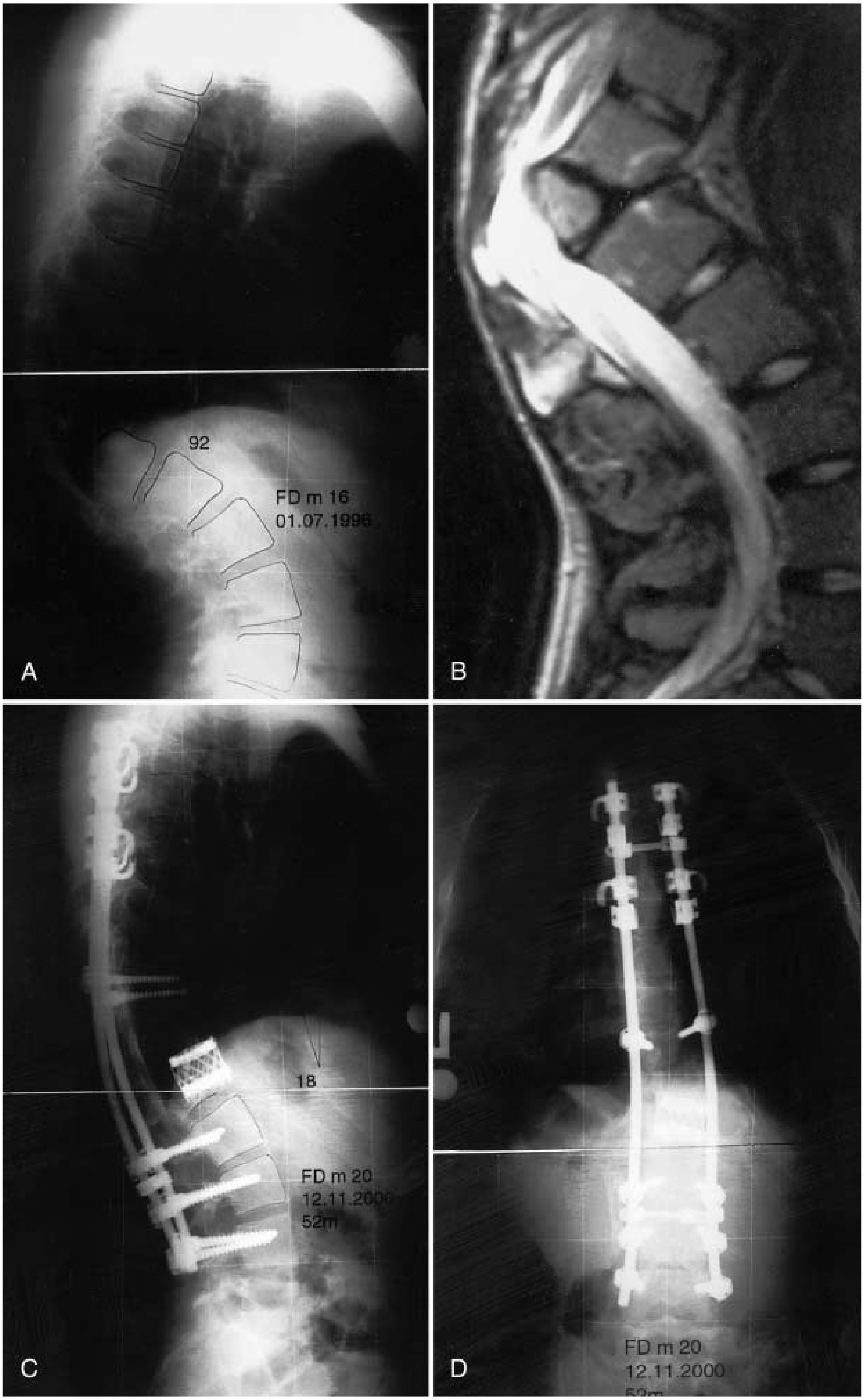

Fig. 2 **a** Preoperative lateral X-ray of patient no. 6 with a 92° kyphosis. **b** Preoperative magnetic resonance imaging (MRI) in the sagittal plane displaying spinal stenosis and congenitally malformed vertebra. **c,d** Postoperative X-rays at the end of the 52nd month

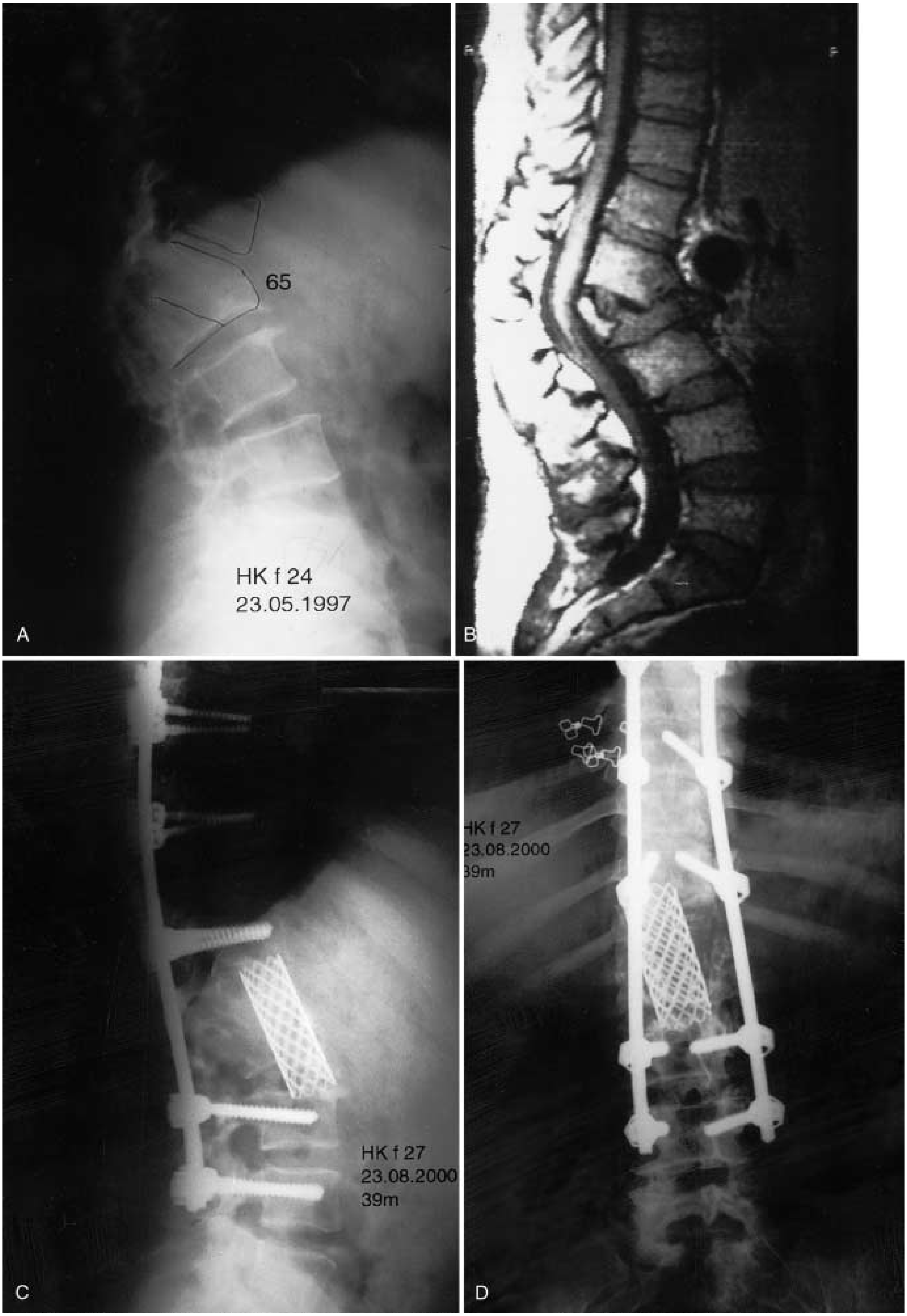

Fig. 3 **a** Preoperative lateral X-ray of patient no. 7 caused by tuberculous spondylitis sequela. **b** Preoperative magnetic resonance imaging (MRI) of the same patient in the sagittal plane displaying post-infectious spinal destruction. **c,d** Postoperative X-rays at the end of the 39th month

Table 2 Results of the subjective patient questionnaire

Case	Pain		Function		Appearance		Outcome	Would you undergo surgery again?	Would you recommend surgery?
	Pre-operative	Post-operative	Pre-operative	Post-operative	Pre-operative	Post-operative			
1	1	4	2	4	1	5	4	Yes	Yes
2	2	4	3	4	2	5	4	Yes	Yes
3	3	5	4	5	1	4	5	Yes	Yes
4	2	4	3	5	2	4	5	Yes	Yes
5	2	5	4	5	1	5	5	Yes	Yes
6	3	5	4	5	2	5	5	Yes	Yes
7	2	5	3	5	1	5	5	Yes	Yes
Average	2.14	4.57	3.28	4.71	1.42	4.71	4.71	100%	100%

Pain: 5, little or no pain; 4, mild, intermittent pain; 3, moderate, but manageable pain; 2, moderate with intervals; 1, severe pain.
Function: 5, normal daily activity; 4, moderate daily activity; 3, limited daily activity; 2, rare daily activity; 1, bedridden, no activity.
Appearance and outcome: 5, excellent; 4, very good; 3, good; 2, fair; 1, poor.

screws are tightened and the physiological thoracal kyphosis is reestablished.

Use of an orthosis during the postoperative period depends on the quality of bone and the stability of the fixation.

Results

The mean preoperative kyphosis angle was measured as 76.1° (range, 65°–92°). The mean local kyphosis angle measured during postoperative examination in the sagittal plane was 6° (range, 0°–13°). Complete bony fusion was achieved after a mean follow-up period of 38 months (range, 26–52 months) with a mean loss of correction angle of 2.4°(range, 0°–4°).

The average duration of the surgical procedure was 8.6 h (range, 6.8–12 h). The average length of hospitalization was 14 days (8–22).

The mean perioperative blood loss was 2550 cc (range, 1600–4300 cc). A cell saver machine was used during the operations, and the mean whole blood requirement was 1600 cc (1200–2800 cc).

None of the patients required external orthotic fixation during the postoperative period. None of the patients developed any neurological complication, and no infections were documented.

One patient experienced a postoperative atelectasis and remained intubated on a respiration machine in the intensive care unit for 4 days. The complication resolved completely by respiratory physical therapy.

During the follow-up examination at the end of the 18th month postoperatively, implant failure in one of the rods was observed in one patient. Further radiological examinations revealed non-union at the third lumbar vertebra, distal to the resection segment. Interbody fusion between the third and fourth lumbar levels was performed through an anterior retroperitoneal approach. The final follow-up X-rays showed complete anterior fusion and no additional implant failure. With the exception of this patient, none of the patients had developed implant failure or pseudoarthrosis by the end of follow-up.

The results of the subjective patient questionnaire are listed in Table 2. All of the patients stated that, if they had to make the decision again, they would undergo surgery and they would recommend the same surgery to someone else. Wilcoxon signed-rank statistical analysis showed a significant difference in the subjective extent of improvement in all three areas of pain, function, and appearance (P=0.015, 0.015, 0.016, respectively) in the patients' responses. The overall outcome rating averaged 4.71.

Discussion

Severe and rigid angular kyphosis of the thoracolumbar spine diagnosed in the adult age-group commonly results from neglected or inappropriately treated congenital malformations, vertebral fractures or infections. Compensatory lordotic segments often develop at the proximal and distal of the deformity. All constituents of these complex disorders must be corrected in order to re-establish the sagittal balance of the spinal column. However, appropriate surgical treatment at this stage is mechanically and neurologically difficult.

Rigid, severely angulated kyphotic deformities cannot be corrected without bone resection [12]. Posterior osteotomies have been widely used for this purpose. Various techniques consisting of partial and total posterior wedge osteotomies have previously been described [3, 8, 9, 11, 14, 15, 16, 18]. The apex of the correction axis lies in the anterior surface of the corpus in posteriorly placed osteotomies. This correction results in considerable shortening of the posterior column affecting not only the bony but also the neural tissues. The neural elements can only tolerate this reduction in the height of the posterior col-

umn if the deformity does not exceed 35°–45° [9]. Furthermore, folding of the spinal cord and impinging between the laminae increase the risk of neurological injury. Posterior corrective osteotomies are reported to result in corrections of between 20° and 55° [3, 8, 9, 11, 14, 15, 16, 18].

Anterior resection and distraction results in a posterior displacement of the fulcrum of the correction axis. Severe spinal cord damage due to distraction and a mechanical block to correction due to posterior rigidity are major drawbacks to this procedure. Furthermore, failure rates reaching 50% have precluded the widespread acceptance of anterior resection [2, 10].

The pivot of the correction is located in the spinal cord with the technique described above. Posterior compression carried out at the beginning releases the tightness and prevents the neurological damage related to subsequent anterior distraction. Moreover, no tissue remains resistant to correction because the spinal column is released in all directions at that point. The deformity can be totally corrected by gradual, controlled, compression–distraction manoeuvres.

Limits of the correction are determined by the flexibility of the compensatory curves proximal and distal to the kyphotic segment. A fixed lordotic segment hinders reconstitution of sagittal balance after the apical correction. The solution would be either to correct within the flexibility limits of the compensatory curve or to correct this deformity too. We prefer the latter solution provided by discectomies and bony resections of the lordotic segments during the anterior procedure. The gap formed in the anterior column is closed by posterior distraction and translation.

Anterior fusion applied to adjacent segments of the kyphotic deformity also diminishes the risk of non-union in the apical segment and offers an additional benefit. The non-union in our series most probably resulted from inadequate anterior fusion and was managed by including the adjacent segments in the anterior fusion field.

The third and final stage is essential, because it offers a final correction of the residual deformity and re-establishes the load-sharing system in the spinal column. An effective posterior tension band is needed for this system to be effective and has to take up compression forces anteriorly and tensile forces posteriorly. The logical prerequisite for this „tension band“ principle to function is a reconstructed anterior column that remains stable despite loading.

Simultaneous performance of all these procedures in a single session is theoretically possible but entails considerable technical difficulties. Bony resection and instrumentation is difficult with the patient lying in the lateral decubitus position, because the orientation of the surgeon is inferior when compared to a prone position. In addition, the prone position facilitates correction of a kyphotic deformity, which is used to correct the residual deformity during the third stage of the technique presented here.

One of the most hazardous complications of vertebral osteotomies is damage to neurological tissues. Lehmer and Steffee report a rate of 12.2% minor and 7.3% major neurological compromise resulting from posterior transvertebral osteotomies, which may be related to direct injury to the cord, dural compression or vascular or spinal canal malalignment [9]. Because posterior osteotomy is basically a spine-shortening procedure, dural buckling can result during closure of the osteotomy gap and may lead to impingement of the spinal cord or cauda equina. In contrast, spondylectomy ensures that the fulcrum of the correction axis is retained within the spinal cord, thus precluding further tension or buckling of the cord. Malalignment of the spinal canal is another problem related to posteriorly placed vertebral osteotomies. Following a total spondylectomy, the cord is circumferentially released and this malalignment is avoided.

A three-stage procedure is certainly more time consuming and results in more blood loss and morbidity than a posterior osteotomy. These risks emphasize the importance of patient selection. The three-stage corrective procedure is suitable for selected patients, especially younger ones, who show greater tolerance to combined anterior and posterior procedures. On the other hand, posterior osteotomies should be preferred in the older patient group due to the lower risk of operative morbidity.

Conclusion

Three-stage corrective procedures provide an excellent alternative for complete correction of rigid, angular kyphotic deformities. This operation is more easily tolerated in the younger patient population. The risk of damage to neural tissues is minimal because the correction does not cause any distraction or buckling of the spinal cord. Finally, three-stage correction of severe, angular, kyphotic deformities provides biomechanically superior reconstruction in concordance with the principles of load sharing in the spinal column.

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