Eur Spine J (1998) 7 : 104–110

ORIGINAL ARTICLE

B. J. van Royen
M. de Kleuver
G. H. Slot

Polysegmental lumbar posterior wedge osteotomies for correction of kyphosis in ankylosing spondylitis

Received: 13 May 1997
Revised: 18 August 1997
Accepted: 29 August 1997

B. J. van Royen (✉)
Department of Orthopaedic Surgery,
Free University Hospital,
De Boelelaan 1117,
1081 HV Amsterdam, The Netherlands
Tel. +31-20-4442987;
Fax +31-20-4442357

M. de Kleuver · G. H. Slot
Department of Orthopaedic Surgery,
Sint Maartenskliniek,
Nijmegen, The Netherlands

Abstract Between 1984 and 1993 we treated 21 consecutive patients who had progressive thoracic kyphosis due to ankylosing spondylitis by polysegmental posterior lumbar wedge osteotomies. In 19 patients we used the Universal Spinal Instrumentation System and in the last 2 patients the H-frame. The average correction in 20 of 21 patients at follow-up was 25.6° (range 0°–52°), with a mean segmental correction of 9.5° and a mean loss of correction after operation of 10.7° (range 0°–36°). There were no fatal complications, but in one patient no correction could be obtained during surgery and another patient was reoperated due to lack of correction. Breaking out of screws through the pedicle during compressive correction was seen in seven patients. Implant failure, such as breakage of the threaded rods and/or loosening of the junction between the pedicle screw and the rod, occurred in 9 out of 21 patients. Two patients required reoperation at long-term follow-up. Five out of seven deep wound infections required removal of the implant. Polysegmental lumbar wedge osteotomies for correction of progressive thoracic kyphosis in ankylosing spondylitis is only recommended in patients at a mild stage of the disease with mobile discs and in combination with strong instrumentation.

Key words Ankylosing spondylitis · Osteotomies · Lumbar spine · Complications

Introduction

Ankylosing spondylitis may lead to a severe fixed kyphosis so extreme that the patient cannot stand, sit or lie in comfort. The aims of surgery are to restore the patients' ability to see ahead to the horizon, to relieve compression of the abdominal viscera by the rib margin and to improve diaphragmatic respiration on which these patients often depend.

Smith-Petersen et al. [24] described two- and three-level osteotomies through the articular processes of L1, L2 and L3 with resection of the spinous processes. Correction was achieved by closing the wedge-shaped osteotomies of the posterior elements and elongation of the anterior column by disruption of the anterior longitudinal ligament and disc at one level. Many modifications of this procedure have been described [1–4, 10, 11, 13–15, 17–19, 21, 22, 25]. These anterior open-wedge osteotomies produce a sharp lordotic angle and elongation of the anterior column, and sometimes cause serious complications such as vascular and irreversible neurologic complications [3, 12, 15, 16, 23, 25, 27].

To avoid these complications, Püschel and Zielke [20] introduced a method based on polysegmental posterior lumbar and thoraco-lumbar wedge osteotomies. This method gives a more gradual correction by multiple closing wedges of posterior osteotomies without fracturing of the anterior column. Initially they used Harrington rods with laminar hooks, later, transpedicular screws.

They reported good results in more than 200 patients [7–9, 20, 30]. To our knowledge only one other author [5] published good short-term results, in a report of 16 patients treated with polysegmental lumbar osteotomies for correcting kyphotic deformities in ankylosing spondylitis.

We now report our experience with this technique, and the middle- to long-term results of polysegmental lumbar posterior wedge osteotomies for correction of kyphosis in ankylosing spondylitis.

Patients and methods

From 1984 to 1993 inclusively we treated 21 patients suffering from thoracic or thoraco-lumbar kyphosis secondary to chronic ankylosing spondylitis by polysegmental lumbar posterior wedge osteotomies. The indication for surgical intervention was impairment of function and the social and psychological impact of a severe progressive thoracic kyphosis with loss of horizontal gaze. There were 16 male and 5 female patients. The average age at the time of operation was 42 (range 19–61) years. The patients were followed up for a period of 28–134 months (mean 85 months). At the time of follow-up, three patients had died, respectively 108, 100 and 78 months after operation. The final follow-up of these patients was chosen as the last time they were seen and examined. Eighteen patients were examined for follow-up by an independent third person (B.V.R., M.D.K.). Chart reviews and clinical and radiographic evaluation were performed in all patients. All operations were performed by the same very experienced surgeon (G.S.) using transpedicular screws and internal fixation. The Universal Spinal Instrumentation System (Ulrich, Ulm) was used in 19 patients, and in the last 2 patients the H-frame (Waldemar Link, Hamburg) was used. All patients were operated in the lumbar region from T12 to S1.

The degree of correction and number of selected segmental osteotomies were calculated from an assessment of the clinical deformity in combination with the preoperative radiographs [22]. The first part was done by clinical assessment of the chin-brow to vertical angle when the patient stands with their hips and knees extended. The chin-brow to vertical angle was restored to as close to normal as possible to see ahead to the horizon in comfort, by flexing the knees with the hip joints extended and placing the weight-bearing line through the sacrum and ankle joint. The correction required as planned with this method ranged from 20° to 60° (mean 40°). These values were used as guidelines to make a draft on standing lateral radiographs of the whole spine. The total number of selected segmental osteotomies was calculated by assuming 10° of correction per segment in ankylosing spondylitis [9]. One patient was operated on two segments, four patients on three segments, ten patients on four segments, five patients on five segments and one patient on six segments. In two patients (cases 15 and 17) with extreme osteoporotic bone loss and calcification of the anterior longitudinal ligament a lumbar anterior release was performed before the posterior procedure.

Preoperatively the thoracic kyphosis was measured on standing lateral radiographs of the whole spine and standardized over nine vertebrae. The mean thoracic kyphosis was 66° (42°–110°), with the apex in the high thoracic area. Decreased motion or ankylosis of the hips associated with a flexion deformity was treated in four patients with a bilateral or unilateral total hip replacement. All patients were preoperatively evaluated by a pulmonologist. In eight patients additional respiratory function tests were performed. All showed some restrictive pulmonary obstruction which did not, however, preclude operative intervention.

Surgical technique

The patients were operated in a prone position on an inclined radiolucent table under general anaesthesia. Care was taken not to injure the ankylosed neck. In most of the patients intubation by fibreoptic laryngoscope was necessary. The chest and pelvis were supported on special firm foam blocks, which leave the abdomen hanging free, thus reducing intra-abdominal pressure and venous stasis. Hypotensive anaesthesia was used in all patients. All patients received antibiotic prophylaxis with an intravenous injection of 1500 mg cefuroxime at the induction of anaesthesia, and a second and third dose of 750 mg cefuroxime was administrated intravenously after 8 and 16 h respectively. The required area at the lumbar and thoraco-lumbar spine was exposed through a midline incision. The paraspinal muscles were stripped sub-periosteally from the spinous processes laterally to the tips of the transverse processes at the level of the pre-planned osteotomies. In most cases the spinous processes were excised. A 5- to 7-mm posterior wedge-shaped osteotomy was performed with resection of the interlaminar space including the original inferior and superior articular processes and a part of the floor and the roof of the intervertebral foramen. These osteotomies were directed latero-cranially, with an angle of approximately 35° to the horizontal (Fig. 1). The number of osteotomies were performed as planned pre-operatively. After completion of the osteotomies almost spontaneous correct alignment of the spine was achieved due to the effect of gravity. Subsequently, transpedicular screws were inserted through the centre of the pedicles parallel to the upper end-plates, converging toward the midline. In extreme osteoporotic bone the anterior cortex of the vertebral body was penetrated. Screw location was controlled by intraoperative radiographs or image intensification. To establish definitive correction the threaded rods were fixed onto the middle screws and the osteotomies were further closed by slowly extending the table and elevating the legs of the patient. Further gradual correction was achieved by tightening the nuts on the threaded rods against the screw heads towards the centrally positioned screws. During all stages of the procedure the nerve roots and cauda equina were continually visualized and inspected. A physiological lordosis of the lower thoracic and lumbar spine was achieved. No monosegmental gapping or elongation of the anterior column and related structures was supposed to occur. After tightening the fixation system in compression, usually the wedges were obliterated and the spondylodesis was completed by applying bone chips from the resected bone wedges over the laminae. Closure was routine

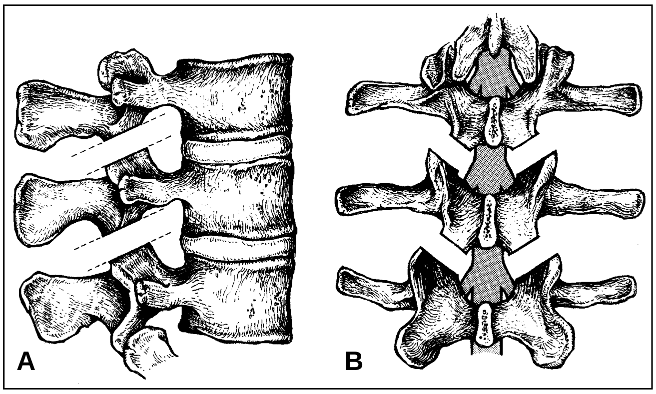

Fig. 1A, B Diagrams of the polysegmental dorsal lumbar osteotomies. **A** Lateral view outlining the bone blocs to be resected through the original facet joints in the direction of the interspinal foramen. **B** Posterior view

Table 1 Clinical data and results of treatment in 21 patients [*USIS* Universal Spinal Instrumentation System; (*a*) deep infection, (*b*) superficial infection, (*c*) implant failure: rod breakage, (*d*) implant failure: loosening of nuts, (*e*) pedicle fracture, (*f*) neuropraxia, (*g*) dura lesion, (*r*) reoperation]

Patient (sex)	Age (years)	Follow-up (months)	Chin-brow angle (degrees)	Level of osteotomy	Instrumentation used	No. of osteotomies	Correction (degrees)				
							Post-op	Segmental	Follow-up[a]	Loss	Complications
1 (M)	31	134	30	L2-L5	USIS	3	57	19	54	3	(c), (f)
2 (M)	45	–	40	T12-L4	USIS	4	0	–	0 (33)		(r)
3 (F)	33	124	40	L1-L5	USIS	4	55	13.8	48	7	(e)
4 (M)	54	67	20	L2-L4	USIS	2	36	18	31	5	(a)
5 (M)	47	118	30	L3-S1	USIS	3	23	7.7	21	2	(a), (f)
6 (M)	19	117	30	L1-L5	USIS	3	7	2.3	0	7	(e)
7 (F)	58	109	40	L2-S1	USIS	4	33	8.3	22	11	(c), (e), (g)
8 (M)	25	97	40	L1-L5	USIS	4	28	7	28	0	(e), (f)
9 (F)	41	118	50	L1-S1	USIS	5	46	9.2	25	21	(c), (r)
10 (M)	60	90	50	L1-S1	USIS	5	45	9	9	36	(a), (c), (d), (e)
11 (M)	61	92	40	L1-L5	USIS	4	39	9.8	28 (39)	11	(b), (e), (r)
12 (M)	43	82	50	L1-S1	USIS	5	36	7.2	3 (49)	33	(c), (d), (r)
13 (M)	40	81	40	L2-S1	USIS	4	45	11.3	33	12	(a)
14 (F)	29	75	60	T12-S1	USIS	6	68	11.3	52	16	(a), (d)
15 (M)	47	80	50	T12-L5	USIS	5	30	6	27	3	(a), (d), (e)
16 (M)	39	70	30	L1-L4	USIS	3	36	12	19	17	(f), (g)
17 (M)	42	73	40	L2-S1	USIS	4	49	12.3	35	14	(b), (c), (d)
18 (M)	35	57	40	T12-L4	USIS	4	33	8.3	22	11	(a)
19 (M)	48	54	30	L2-L5	USIS	3	21	9	20	1	(c)
20 (M)	39	28	50	T12-L5	H-frame	5	22	4.4	19	3	–
21 (F)	50	34	40	L1-L5	H-frame	4	16	4	16	0	–

[a] Additional correction after reoperation in *parentheses*

over a vacuum drainage system. A well-molded posterior plaster shell was then applied. In addition, the next day an anterior plaster shell was made so the patient could be rolled over. Two weeks after operation the patients were mobilized in a thoraco-lumbo-sacral plaster cast with one hip extension for 4–6 months. In nine patients considered to be at risk of developing hip stiffness the plaster cast was changed at 3 months for one with a hip extension on the contralateral side.

Results

The clinical data of all 21 patients are listed in Table 1. The mean operating time was 194 min (range 125–270 min) and the mean blood loss was 1425 ml (range 550–4000 ml). Radiographs of the lumbar spine immediately after operation showed that in 20 of 21 patients correction had been achieved by closure of the posterior osteotomies and segmental opening of the anterior disc spaces (Fig. 2). In one patient no correction was obtained during surgery (case 2, Table 1). The mean postoperative correction in the operated lumbar area of the 20 patients was 36.3° (range 7°–68°) and the mean correction per segment was 9.5° (range 2.3°–19°). At follow-up, radiographs of all patients showed a correction ranging from 0° to 52° (mean 25.6°) with a mean loss of correction in the operated area of 10.7° (range 0°–36°).

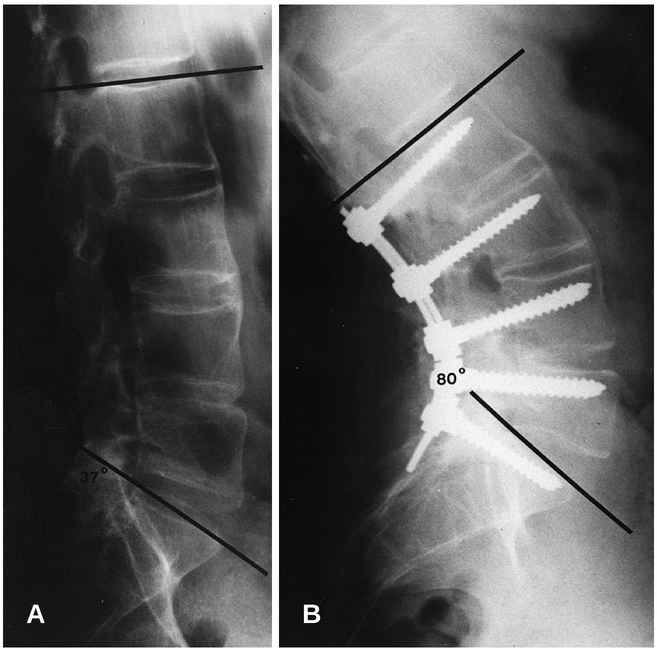

Fig. 2A, B Pre- and postoperative lateral radiographs (case 13) with a follow-up of 12 months after polysegmental lumbar osteotomies and correction with the USIS transpedicular instrumentation. There has been 43° of correction

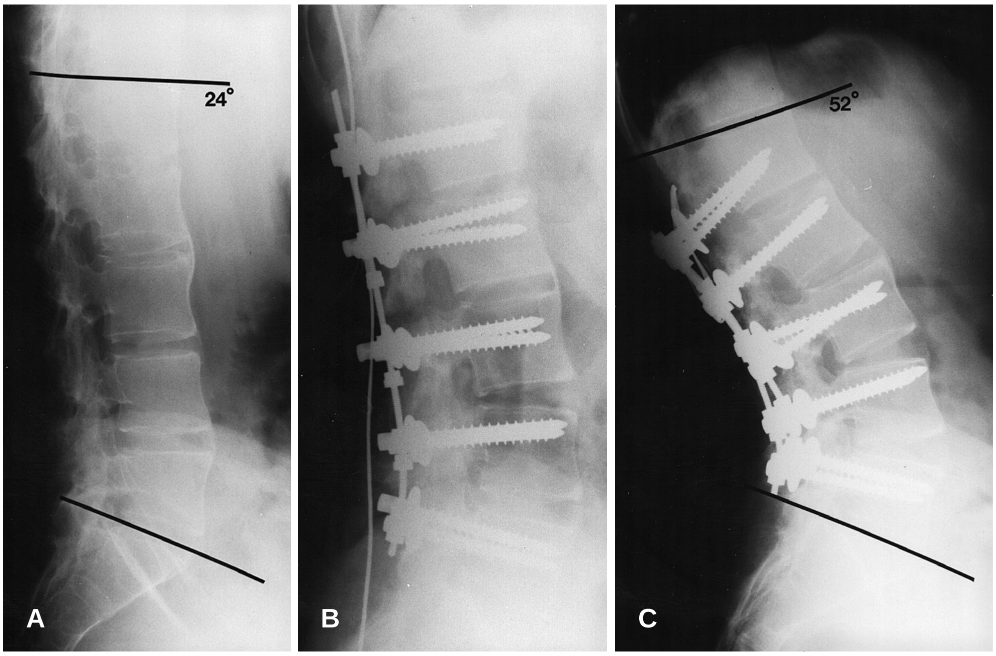

Fig. 3A–C Pre-, intra- and postoperative lateral radiographs of polysegmental osteotomies with transpedicular fixation (case 8). Screw location intraoperatively appears adequate. After correction and tightening the instrumentation in compression, fracturing of the pedicle and breakout of the screw in L1 occurs

Intra-operative complications and difficulties

No fatal complications were observed. The patient in whom no correction could be obtained during operation (case 2) required an additional anterior release, anterior correction and interbody fusion the day after the posterior procedure. An additional monosegmental correction of 33° was achieved. Another patient (case 11) required an additional anterior procedure at the operated area with dorsal refixation 2 weeks after the initial procedure. Breakout of the screws with pedicle fracture caused an inadequate correction. In two patients a dural tear occurred during operation due to dural adhesion to the ossified ligamentum flavum. The dura was sutured and both patients recovered uneventfully. Due to lack of screw fixation in extreme osteoporosis, a small portion of bone cement was inserted twice in a vertebral body through the pedicle before screw placement.

Early postoperative complications (complications diagnosed postoperatively but within the first 3 postoperative months)

Pedicle fracturing with breakout of the screws during tightening of the instrumentation was diagnosed postoperatively in seven patients (33%) (Fig. 3). In addition, in four patients complete reversible sensory symptoms of root irritation was diagnosed. There were seven deep wound infections (33%) diagnosed within the first 3 months and removal of the instrumentation was necessary in five patients 1–4 years after the operation. At time of removal of the implants a solid fusion was found. Two other patients developed a superficial skin infection under the plaster and were successfully treated by antibiotics and changing the plaster cast.

Late postoperative complications (complications diagnosed after 3 months postoperatively)

Unilateral or bilateral breakage of the threaded rods was seen in seven patients (33%). All were instrumented with the USIS system. Failure of instrumentation was diagnosed between the 3rd and 16th month postoperatively. Most of the rods broke in the highest or lowest level of instrumentation. In three of these seven patients and in two other cases the rod dislocated out of the nuts (Fig. 4). Two patients needed reoperation after more than 5 years. One patient (case 9) had loss of correction due to implant failure and developed again a progressive thoracic kyphosis due to cranial decompensation. An additional anterior thoraco-lumbar correction and interbody fusion cranial to the previous fusion, in combination with a dorsal refixation, was performed 6 years after the primary intervention. Another patient (case 12) was treated by a closing-wedge lumbar osteotomy with partial corporectomy of L4 and transpedicular fixation [26] 6 years and 9 months after a posterior polysegmental procedure. Implant failure and progressive loss of correction was the indication for re-intervention.

Discussion

Polysegmental lumbar osteotomies for correction of thoracic kyphosis in ankylosing spondylitis has been recom-

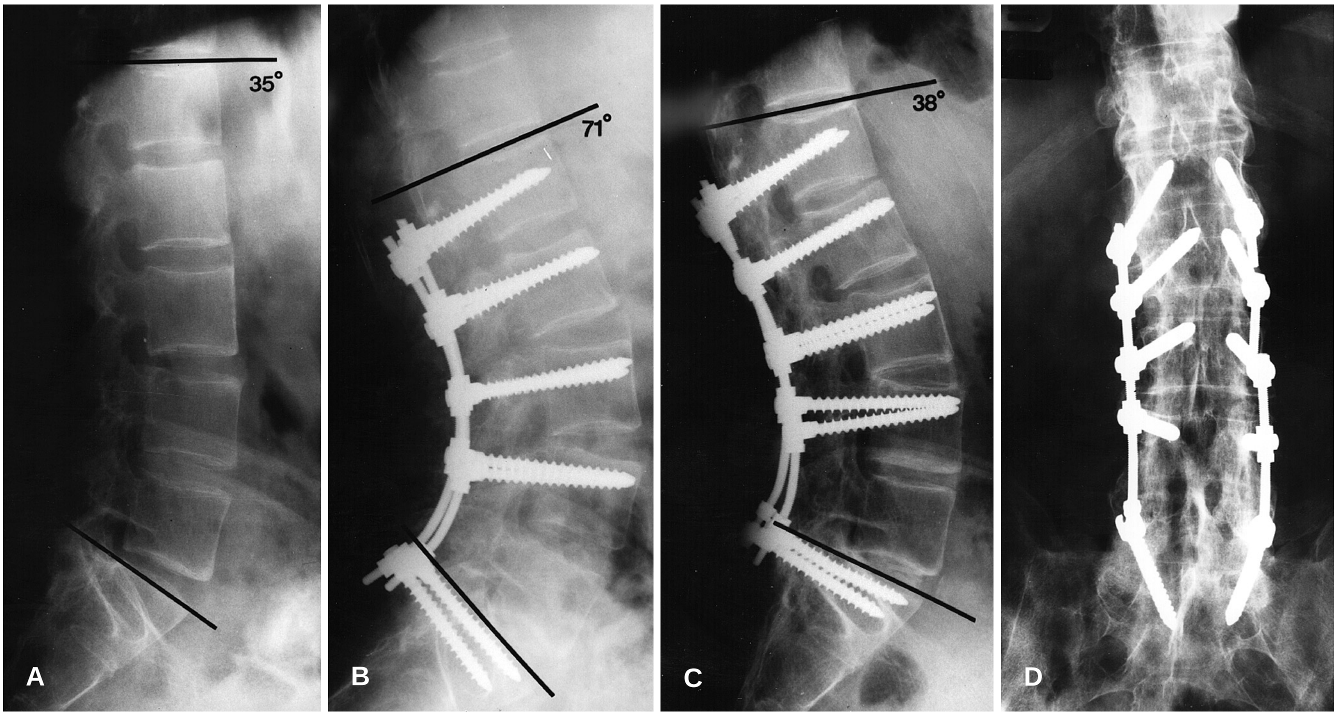

Fig. 4A–D Pre- and postoperative lateral radiographs with a follow-up of 82 months after polysegmental lumbar osteotomies and correction with the USIS transpedicular instrumentation (case 12). There has been 36° of correction. Loss of correction is 33° at follow-up. Note the rod breakage in the highest two levels and failure at the junction of the pedicle screw and the rod in the lowest level of the USIS instrumentation

mended to produce a harmonious lordosis without the risks of a monosegmental anterior opening-wedge osteotomy [5, 7–9, 20, 29, 30]. Correction is achieved by compressive dorsal shortening of the convex side of a long curve as demonstrated in anterior scoliosis surgery by Dwyer [6] and Zielke et al. [31]. The major deformity is a thoracic kyphosis, but only in the lumbar or thoraco-lumbar region is it feasible to perform sufficient correction, because the rib cage would prevent enough correction at the kyphotic deformity itself. Instrumentation and correction in polysegmental posterior wedge osteotomies are advised only in the lumbar region from T12 to S1 [9]. In addition, a maximum correction can be achieved when the correction is performed as low as possible in the lumbar spine [26]. Wilson and Turkell [29] first reported on a patient treated by polysegmental lumbar posterior wedge osteotomies alone. Simmons [21] started to use internal fixation devices in polysegmental thoracic posterior wedge osteotomies. He successfully used a Harrington compression instrumentation and an anterior strut in a thoracic kyphotic patient with ankylosing spondylitis. However, failure of the Harrington device occurred in using this instrumentation in the lumbar spine [1, 7, 8, 20]. Hehne et al. [9] performed polysegmental osteotomies with segmental transpedicular fixation using the USIS instrumentation in 177 patients with kyphotic deformities at various stages of ankylosing spondylitis. They reported an average correction of 44° ± 16°, with no nonunions. Loss of correction was minimal at follow-up. There was a correction of 9.5° per segment. Implant breakage occurred only in four cases. Chen [5], using the same technique in 16 patients, reported an average correction of 25.8°, with a segmental correction of 5°, and a loss of correction of 0.9° at 6–24 months follow-up. He noted early rod breakage in four patients (25%).

We experienced a large number of complications with this multilevel technique and using the USIS instrumentation for correction of thoracic kyphosis in ankylosing spondylitis. The average correction of 25.6° at follow-up was comparable with the results of Chen [5], but low as compared with the results of Hehne et al. [9]. Although the use of transpedicular segmental screw fixation prevented monosegmental sharp-angled lordosation, we observed a high rate of method- and implant-related complications. The full angular correction of the lumbar spine as determined preoperatively was not possible in 13 of the 21 patients (62%). Reoperations were indicated in two patients. In both patients no or inadequate correction was achieved during primary surgery. In the postoperative period breaking out of the screws through the pedicle was seen in seven patients. This complication has never been reported before. In nine patients (43%) the postoperative complications were caused by failure of the instrumentation, such as rod breakage, loosening of the nuts and luxation of the rods. There was a loss of correction of more than 10° in ten patients. In two cases a new correction was indicated after 6 years, and 6 years and 9 months respectively.

Fig. 5A, B Pre- and postoperative lateral radiographs of the full spine using H-frame instrumentation. On the preoperative radiograph the lordotic curve disappears and balance is achieved by flexion in the knee joints and tilting of the pelvis, causing the sacrum to become vertical. Balance and sacral inclination are restored postoperative

The biomechanical aim of correction is to place the weight-bearing line through or posterior to the sacrum and the osteotomies so that gravity will maintain the correction and ensure rapid fusion and consolidation. Insufficient correction or loss of correction in the presence of existing thoracic kyphosis places the fusion zone under tension because of the long lever arm [28], again leading to implant failure and loss of correction. Decompensation cranial to the fusion, as seen in one of our cases, may occur if the fusion zone is too short because kyphosis may progress due to the underlying disease. Frequent early breakage of the 3-mm posterior rods of the USIS instrumentation suggests that these rods may not be strong enough to hold a stable fixation until a fusion is achieved. The stronger H-frame instrumentation, with ductile 6-mm threaded rods, probably provides a better stabilization (Fig. 5). Screw breakout, as seen in seven cases, may be explained by two mechanisms. First, osteoporotic bone loss is a general phenomenon in ankylosing spondylitis. This reduces the grip of screws. Second, calcification of the discs and bridging syndesmophytes will strongly resist the lordotic correction during surgery. Thus very large forces are exerted on the screws and rods, explaining the breakout and rod failure in our cases.

Deep and superficial infections were seen in nine patients (43%) necessitating implant removal in five cases. The cultured organisms varied and there was no association with a time period or environmental problems. We still cannot explain the high infection rate in these patients compared to other extensive surgical spine procedures, such as scoliosis surgery, performed in the same period of time. Many factors may influence the outcome, such as duration of the operation, extensive exposure, insufficient stability of the instrumentation, and/or blood loss. We have the impression that these patients are more vulnerable for infections, although we cannot prove this.

Preoperative anterior release was indicated in two patients. In line with many other authors [10, 11, 13, 21, 25], we agree that a posterior osteotomy alone should not be performed in patients with extreme osteoporotic bone loss, considerable disc calcification or ossification of the anterior longitudinal ligament. Unfortunately, in two other patients an additional anterior release was necessary after the posterior procedure due to failed correction. Radiographic imaging was not conclusive in these cases. Detailed skeletal changes, like the degree of osteoporotic bone loss and syndesmophyte formation, are not precisely visible on standard radiographs. Routine dual-energy X-ray absorptiometry (DEXA) measurements may be indicated to objectify the degree of bone loss. In addition, MR- or CT imaging is needed to visualize the extent of calcification of the anterior longitudinal ligament. However, these proposals have not yet been evaluated as a guideline in patients with ankylosing spondylitis.

Sagittal plane alignment is important in the assessment of the degree of spinal deformity in ankylosing spondylitis. To our knowledge, there still are no reproducible parameters that can be used as a guideline for pre- and postoperative evaluation. Exact reproducible assessment of the whole spine on sagittal radiographs using different techniques such as measurement of the overall sagittal vertical axis or the C7 plumb line, however, is problematic due to the unknown position or tilt of the pelvis, flexion in the hip, knee and ankle joints, the long cassette films, and the indistinct landmarks C7 and S1 (Fig. 5). Estimation of the degree of correction and number of selected segmental osteotomies required, therefore, remains difficult and is based on an assessment of the chin-brow to vertical angle which is projected on preoperative radiographs [22].

Conclusions

We no longer recommend polysegmental lumbar posterior wedge osteotomies as the first choise of surgical treatment for correction of progressive thoracic kyphosis in ankylosing spondylitis. Although this method may be suitable in patients at a mild stage of the disease with mobile discs, which still allows some anterior elongation in combination with a strong instrumentation, most of these patients do not have enough deformity to justify correction. If a polysegmental osteotomy is individually planned in patients with known extreme osteoporotic bone loss and calcification of the anterior longitudinal ligament, an anterior release preceding this procedure is recommended. In such cases, we recommend the transpedicular screws should penetrate the anterior cortex of the vertebral body. Most patients in our clinic are seen at a late stage of the disease with calcification of the discs, bridging syndesmophytes and the classic bamboo spine. A closing-wedge posterior vertebral osteotomy with partial corporectomy of L4 and transpedicular fixation as recently reported [26] is preferred.

Acknowledgements The authors thank Prof. P. I. J. M. Wuisman, M. D., Ph. D., for his critical suggestions and assistance as this manuscript approached its final draft.

References

1. Bradford DS, Schumacher WL, Lonstein JE, Winter RB (1987) Ankylosing spondylitis: experience in surgical management of 21 patients. Spine 12: 238–243. (Erratum (1987) Spine 12: 590–592)
2. Briggs H, Keats S, Schlesinger PT (1947) Wedge osteotomy of the spine with bilateral, intervertebral foraminotomy: correction of flexion deformity in five cases of ankylosing arthritis of spine. J Bone Joint Surg 29: 1075–1082
3. Camargo FP, Cordeiro EN, Napoli MM (1986) Corrective osteotomy of the spine in ankylosing spondylitis. Experience with 66 cases. Clin Orthop 208: 157–167
4. Chapchal G (1949) Operative treatment of severe kyphosis as the result of Bechterew's disease. Arch Chir Ned 1: 57–63
5. Chen PQ (1988) Correction of kyphotic deformity in ankylosing spondylitis using multiple spinal osteotomy and Zielke's VDS instruments. J Formosan Med Assoc 87: 692–698
6. Dwyer AF (1969) An anterior approach to scoliosis. J West Pac Orthop Assoc 6: 3–96
7. Halm H, Metz-Stevenhagen P, Zielke K (1995) Results of surgical correction of kyphotic deformities of the spine in ankylosing spondylitis on the basis of the modified arthritis impact measurement scales. Spine 20: 1612–1619
8. Hehne HJ, Zielke K (1990) Die kyphotische Deformität bei Spondylitis ankylosans. Klinik, Radiologie und Therapie. In: Schulitz K-P (ed) Die Wirbelsäule in Forschung und Praxis. Hippocrates, Stuttgart, Band 112, pp 32–69
9. Hehne HJ, Zielke K, Böhm H (1990) Polysegmental lumbar osteotomies and transpedicled fixation for correction of long-curved kyphotic deformities in ankylosing spondylitis. Report on 177 cases. Clin Orthop 258: 49–55
10. Herbert JJ (1948) Vertebral osteotomy, technique, indications and results. J Bone Joint Surg [Am] 30: 680–689
11. Herbert JJ (1959) Vertebral osteotomy for kyphosis, especially in Marie-Strümpell arthritis. J Bone Joint Surg [Am] 41: 291–302
12. Klems VH, Friedebold G (1971) Ruptur der Aorta abdominalis nach aufrichtungsoperation bei Spondylitis ankylopoetica. Z Orthop Ihre Grenzgeb 108: 554–563
13. La Chapelle EH (1946) Osteotomy of the lumbar spine for correction of kyphosis in a case of ankylosing spondylarthritis. J Bone Joint Surg 28: 851–858
14. Law WA (1959) Lumbar spine osteotomy. J Bone Joint Surg [Br] 41: 270–278
15. Law WA (1969) Osteotomy of the spine. Clin Orthop 66: 70–76
16. Lichtblau PO, Wilson PhD (1956) Possible mechanism of aorta rupture in orthopaedic correction of rheumatoid spondylitis. J Bone Joint Surg [Am] 38: 123–127
17. McMaster PE (1962) Osteotomy of the spine for fixed flexion deformity. J Bone Joint Surg [Am] 44: 1207–1216
18. McMaster MJ, Coventry MB (1973) Spinal osteotomy in ankylosing spondylitis: technique, complications, and long-term results. Mayo Clin Proc 48: 476–486
19. McMaster MJ (1985) A technique for lumbar spinal osteotomy in ankylosing spondylitis. J Bone Joint Surg [Br] 67: 204–210
20. Püschel J, Zielke K (1982) Korrekturoperation bei Bechterew-Kyphose. Indikation, Technik, Ergebnisse. Z Orthop Ihre Grenzgeb 120: 338–342
21. Simmons EH (1977) Kyphotic deformity of the spine in ankylosing spondylitis. Clin Orthop 128: 65–77
22. Simmons EH (1992) Ankylosing spondylitis: surgical considerations. In: Rothman RH, Simeone FA (eds) The spine, vol 2, 3rd edn. Saunders, Philadelphia, pp 1447–1511
23. Simmons EH (1994) Relation of vascular complication to the level of lumbar extension osteotomy in ankylosing spondylitis. Presented at the 61st Annual Meeting of the American Academy of Orthopaedic Surgeons, New Orleans
24. Smith-Petersen MN, Larson CB, Aufranc OE (1945) Osteotomy of the spine for correction of flexion deformity in rheumatoid arthritis. J Bone Joint Surg [Am] 27: 1–11
25. Styblo K, Bossers GT, Slot GH (1985) Osteotomy for kyphosis in ankylosing spondylitis. Acta Orthop Scand 56: 294–297
26. Van Royen BJ, Slot GH (1995) Closing-wedge posterior osteotomy for ankylosing spondylitis. Partial corporectomy and transpedicular fixation in 22 cases. J Bone Joint Surg [Br] 77: 117–121
27. Weatherley C, Jaffray D, Terry A (1988) Vascular complications associated with osteotomy in ankylosing spondylitis: a report of two cases. Spine 13: 43–46
28. White AA, Panjabi MM, Thomas CL (1977) The clinical biomechanics of kyphotic deformities. Clin Orthop 128: 8–17
29. Wilson MJ, Turkell JH (1949) Multiple spinal wedge osteotomy: its use in a case of Marie Strümpell spondylitis. Am J Surg 77: 777–782
30. Zielke K, Rodegerds U (1985) Operative Behandlung der fixierten Kyphose bei „Spondylitis ankylosans". Indikation, Komplikationen und Ergebnisse. Vorläufiger Bericht über 78 Fälle. Z Orthop Ihre Grenzgeb 123: 679–682
31. Zielke K, Stunkat R, Beaujean F (1976) Ventrale Derotationsspondylodese. Vorläufiger Ergebnisbericht über 26 operierte Fälle. Arch Orthop Unfall Chir 85: 257–277