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Closing Wedge Osteotomy Versus Opening Wedge Osteotomy in Ankylosing Spondylitis With Thoracolumbar Kyphotic Deformity

Kao-Wha Chang, MD, Ying-Yu Chen, MD, Chien-Chung Lin, MD, Hsiang-Lan Hsu, BA, and Ke-Chun Pai, BA

Study Design. Retrospective.

Objectives. To compare lumbar posterior opening wedge osteotomy (OWO) and closing wedge osteotomy (CWO) in patients with thoracolumbar kyphotic deformity attributable to ankylosing spondylitis.

Summary of Background Data. OWO and CWO have been used to correct ankylosing spondylitis-related kyphotic deformity, but the ideal surgical procedure remains controversial.

Methods. Sixty-six patients underwent OWO, and 51 underwent CWO (102 male, 15 female; mean age, 34.8 years; age range, 17–55 years). Radiographic results, complications, and patient satisfaction were analyzed over a mean follow-up of 3.6 years (range, 2.1–5.3 years)

Results. For OWO and CWO, mean operative times were 183 and 218 minutes, and mean blood losses were 1101 and 1915 mL, respectively. Lumbar lordosis increased by 37° with OWO *versus* 36° with CWO group, as shown on final radiographs. Sagittal imbalance improved 80 and 77 mm with OWO and CWO, respectively. Complications included delayed union in three patients and a broken rod at the osteotomy site in the OWO group. Six transient neurologic deficits occurred overall. No mortality or major complications occurred. Five patients developed junctional kyphosis (two undergoing OWO, three undergoing CWO), and all required repeat operation. Satisfactory clinical outcomes were achieved in both groups.

Conclusion. Both OWO and CWO were safe and enabled substantial correction, with good clinical results. CWO resulted in a significantly longer operative time and more bleeding but offered fewer instances of paralytic ileus or delayed union with a broken rod.

Key words: ankylosing spondylitis, closing wedge, osteotomy, opening wedge osteotomy. **Spine 2005;30: 1584–1593**

Ankylosing spondylitis (AS) causes characteristic spinal deformities such as flattening of the normal lumbar lordosis and an increasing smooth thoracic kyphosis with the head and neck thrust forward. Occasionally, flexion increases at the cervicothoracic junction. Eventually, the whole spine undergoes bony ankylosis in this deformed position. The chief complaint is an inability to look straight ahead. The kyphotic deformity may restrict activities of daily living and also cause psychological effects. In severe cases, visceral compression may cause intra-abdominal complications.

Corrective spinal osteotomy may be considered to restore the patient's balance and ability to see straight ahead. The intervention should also improve diaphragmatic respiration and relieve visceral compression caused by the inferior margin of rib cage. In AS, the spinal deformity is mostly a combination of a thoracic hyperkyphosis and a flattening of the lumbar lordosis. The kyphosis is best corrected with lumbar lordosating osteotomy, because thoracic correction is strongly limited by ankylosis of the costovertebral joints.[1–8] Overall correction is greatest with a lumbar intervention. The relatively narrow thoracic spinal canal renders the midthoracic spinal cord more vulnerable to perioperative injury than the cauda equine in its spacious spinal canal.

Two operative techniques have been described: open wedge osteotomy (OWO)[1–3,7–13] (Figure 1) and closing wedge osteotomy (CWO)[14–21] (Figure 2). Some prefer CWO because of the high complication and mortality rates associated with OWO.[14,15,21] However, others challenge this association.[3,8,12,13] Since 1998, we have applied both techniques. We compared outcomes of the two procedures in severe kyphotic deformity attributable to AS.

Materials and Methods

Patients. We retrospectively reviewed 117 AS patients who underwent OWO (n = 66) or CWO (n = 51) for AS-related kyphotic deformity between 1998 and 2002. We made the diagnosis of AS by radiographic features, laboratory tests, and clinical features. Radiographic features include symmetrical and bilateral subchondral erosions and sclerotic change of sacroiliac joint, widespread with irregular bridging of the joint or complete obliteration of the joint, marginal syndesmophytes or enthesophytes, and bamboo spine appearance. Laboratory studies include HLA-B27 antigen and erythrocyte sedimentation rate. The clinical features include the first manifestation in a young adult with symptoms including low back pain and unilateral or bilateral buttock, hip, and thigh pain; classic morning stiffness; limited chest expansion, subjective difficulty in breathing, and tightness of chest wall; pain, stiffness, and

From the Taiwan Spine Center and Department of Orthopaedic Surgery, Armed Forces Taichung General Hospital, Taiwan, Republic of China

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Address correspondence and requests for reprints to Kao-Wha Chang, MD, Taiwan Spine Center and Department of Orthopaedic Surgery, Armed Forces Taichung General Hospital, Taiwan, No.348, Sec.2, Chung-Shan Rd, Taiping City, Taichung Hsein, Taiwan, Republic of China; E-mail: iscspine@ms45.url.com.tw

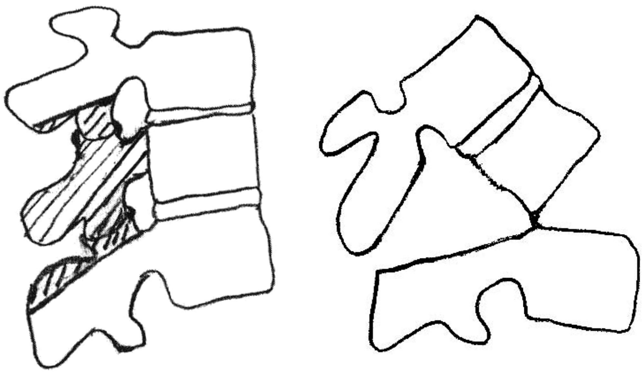

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Figure 1. Diagrams of OWO. **A,** Lateral view outlines the bone block to be resected. Total pediculectomy is to avoid nerve root compression by remaining pedicle because of sagittal rotation of the cranial vertebral column in OWO.[38] **B,** Postoperative lateral view shows that correction is achieved by hinging on the posterior border of vertebral body, closing the posterior osteotomy, and creating an open wedge of the anterior column.

limited motion of the spine; kyphotic deformity; associated synovitis of a peripheral joint, usually the hips, shoulders, knees, or wrists; and several extraskeleton manifestation of AS including recurrent iritis, aortitis, and carditis. We rely on the characteristic radiographic features to confirm the diagnosis of AS. In this study the characteristic enthesophytes or bamboo spine were seen in all patients. Patients who underwent surgery for pseudarthrosis, fractures, or diskitis were excluded. The chief complaint for most patients was an inability to look straight ahead or lie flat. The deformity restricted their interpersonal communication and ability to drive a car, walk, and even shave. In some patients, severe deformity caused compression of the abdominal viscera, with indigestion. Some of these patients had significant psychosocial impairment.

Clinical Data. Clinical records were reviewed for demographic data (Table 1), operation time, intraoperative blood loss, and complications. Patients with follow-up longer than 2 years answered a Scoliosis Research Society (SRS)–24 Outcome questionnaire[22,23] at final follow-up.

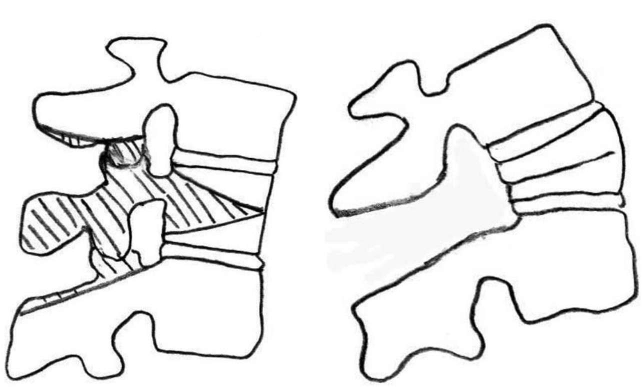

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Figure 2. **A,** Lateral view outlines the bone block to be resected. **B,** Postoperative lateral view shows that correction is achieved by hinging on the anterior cortex of the vertebral body and closing the intravertebral osteotomy.

Table 1. Patient Demographic Data

Data	OWO (n = 66)	CWO (n = 51)
Age (yrs)	33.5 ± 8 (17–49)	36.3 ± 7 (19–55)
Male-to-female ratio	57:9	45:6
Follow-up (yrs)	3.6 ± 1.1 (2.1–5.3)	3.5 ± 1.3 (2.2–5.1)

Note. Data are the mean ± SD (range) unless otherwise noted.

Standing anteroposterior and lateral radiographs were obtained before and immediately after surgery and at last follow-up (minimum 2 years). Measurements included thoracic kyphosis, lumbar lordosis, and the C7 sagittal plumb line (distance between the vertical line from the center of the C7 body to the posterosuperior corner of S1 on lateral radiographs).

Clinical, radiographic, intraoperative, and postoperative data were compared between OWO and CWO by using the Mann-Whitney *U* test with a significance level of 0.05. Preoperative clinical and radiographic data did not differ between the groups.

Surgical Techniques. All procedures were performed by monitoring somatosensory-evoked potentials. After receiving general anesthesia, patients were placed prone on the operating table, which was flexed in a reverse *V* shape. The lumbar spine was exposed through a midline incision. Subperiosteal dissection was performed to expose the posterior elements as far laterally as the transverse processes. Pedicle screws were inserted into several segments above and below the osteotomy level.

With CWO, laminectomy and facetectomy were done. After both pedicles to be resected were identified (almost always at L2), holes were made through them to the vertebral body, and curettes were used to enlarge the holes. The transverse processes were excised at their bases. With angle curettes, the cancellous bone was pushed anteriorly into the body to create a cavity. The posterior and lateral cortex of the body was thinned with angled curettes, and both pedicles were enucleated with a small osteotome. The posterior cortex was then pushed down into the body. A rongeur was used to resect the appropriate lateral cortex bilaterally. Towel clamps were used to firmly grasp the cranial and caudal spinous processes while the operating table was extended to gradually close the osteotomy (Figure 1).

The technique for OWO was basically that described by Smith-Peterson *et al*[7] The preferred site was distal to the first lumbar vertebra and usually between the second and third lumbar vertebrae. An oblique osteotomy was made in the spinous processes one level above and below the central vertebra. Laterally, the osteotomy line extended to the medial border of the facet articulations. Osteotomy with removal of the bony elements delineated an ovoid opening equal to the height of two vertebral bodies and wide enough to include the facet joints. The vertebral canal was enlarged proximally and distally to permit the introduction of the tip of the little finger. The bone was cut carefully to avoid bone spicules and to protect the nerve tissue from damage. Two osteotomes were introduced on each side of the opening, delineating a bone wedge about 2 cm wide, including the intervertebral joint. Extraction of the bone wedge—including the articular facets—opened the intervertebral foramens, avoiding compression of the nerve roots during correction. It was important to remove enough bone from the pedicles above and below the intervertebral foramens to ensure that the nerve roots were not pinched as the osteotomy was closed. Fracture of anterior vertebral column usually occurred by gravity of the patient's trunk or by light pushing on the back after the osteotomy. The audible crack was related to the fracture of the calcified anterior longitudinal ligament. Sometimes, fracture did not occur, so a fluoroscopically guided osteotome was punched through the disc at the osteotomy level to penetrate the anterior longitudinal ligament bilaterally. A light push on the patient's back easily accomplished the fracture. Sudden force was avoided during correction. Elevation of the head and pelvic ends of the operating table caused the spine to hinge at the osteotomy level. Closing of the lateral osteotomies and shortening of the vertebral canal opening were observed. It was important to ensure that the site of eventual closure, about which correction would occur, was anterior to the osteotomy site. The cauda equine relaxed as the spinal column was extended and the osteotomy closed (Figure 2). After we completed the correction, resected bone was introduced on the raw bone surfaces in the form of cancellous bone chips.

The aim of both osteotomies was to achieve the best possible sagittal balance. Although we closed the osteotomy in both procedures, the correction proceeded until the patient's shoulder reached the same horizontal line as that of the pelvis. Thus, we could approximate the C7 plumb line to S1 (Figures 3 and 4). After we confirmed that the exiting nerve roots were free, we stabilized the pedicle screws. A wake-up test was performed during the closure in all patients.

Postoperative Management. Postoperative management was the same in both groups. The patients were allowed to sit up in bed 24 hours after surgery, and they were allowed to ambulate with a custom-made plastic thoracolumbosacral orthosis (TLSO) after 3 days. The TLSO was used for approximately 3 to 6 months.

Surgical Decision Making. We performed the osteotomies distal to the first lumbar vertebra (usually at L2 for CWO and L2–L3 for OWO) because the vertebral canal is relatively spacious at this level, helping to prevent cord injury. This site is also far enough from the sacrum to allow for application of the internal fixation device. The choice of osteotomy depended on the elasticity of the aortic wall and the quality of the bone at the level of osteotomy. We did formal radiologic evaluation with dual energy x-ray absorptiometry (DEXA) scans before surgery to investigate and record patients' bone density for reference. The quality of the bone can be felt during surgery by using surgical tools such as a bone rongeur or curette. If the bone was soft and osteoporotic, we performed CWO because intravertebral wedge osteotomy was easier. OWO was performed in patients without osteoporosis because the middle column of vertebral body needed to be hard enough to act as a hinge without collapsing during the pivotal corrective procedures. We believed that tissue elasticity was the most important factor in determining whether OWO would lead to aortic damage. Therefore, we did not consider OWO in patients older than 50 years of age and in those with atheromatous deposits and calcification in the aortic wall according to preoperative plain radiographs.

Results

Operative Procedure

OWO was performed between the first and second lumbar vertebrae in five patients, between the second and third lumbar vertebrae in 55, and between the third and fourth lumbar vertebrae in six (Table 2). CWO was performed at the second lumbar vertebrae in 47 patients and at the third lumbar vertebrae in four. Compared with CWO, OWO resulted in a significantly shorter operative time and less bleeding ($P < 0.05$, Mann-Whitney U test). There are only 3 patients whose age was above 50 in the group of CWO. The bleeding and operation time of the 3 patients were slightly above and below the mean. We believe bleeding or operation time is not related to the patients' age in this study.

Radiographic Results

Postoperative radiographs showed that all corrections with OWO occurred with rupture of the anterior longitudinal ligament and opening of the anterior disc space at the osteotomy level (Table 3). With CWO, all correction was achieved with closure of the intravertebral osteotomy.

With OWO and CWO, thoracic kyphosis did not significantly differ on preoperative, postoperative, and last follow-up images. The lordotic angle did not significantly change between the immediate postoperative and last follow-up visits, though sagittal balance did. The groups did not significantly differ in terms of the correction or loss of lumbar lordosis and sagittal balance.

During follow-up, five CWO patients and eight OWO patients noted deterioration in their posture caused by increasing flexion deformity at other sites. Four had increasing flexion at the cervicothoracic junction: Two were not severe enough to require treatment, and two needed cervical osteotomy at 18 months after their spinal osteotomy. Nine patients had increasing hip pain and flexion contractures. Their initial correction was mostly restored with bilateral total hip replacements at least 12 months after spinal osteotomy. At final follow-up, all patients could look straight ahead but with some loss of sagittal balance.

Complications

Seven dural tears occurred during surgery while the ossified ligamentum flavum was dissected away from the midline before the osteotomy was extended, and the dura was adherent to the ligamentum and could not be separated (Table 4). In two cases, the dura was sutured, and in the other five, Spongostan was placed on it. All seven patients recovered uneventfully. Eleven OWO patients and three CWO patients developed a paralytic ileus, which resolved after a Levin tube was inserted and oral intake restricted. No vascular complications occurred. With OWO group, postoperative pneumonia occurred in two patients and superficial infection in one. With CWO, postoperative pneumonia occurred in one patient and superficial infection in one. All recovered

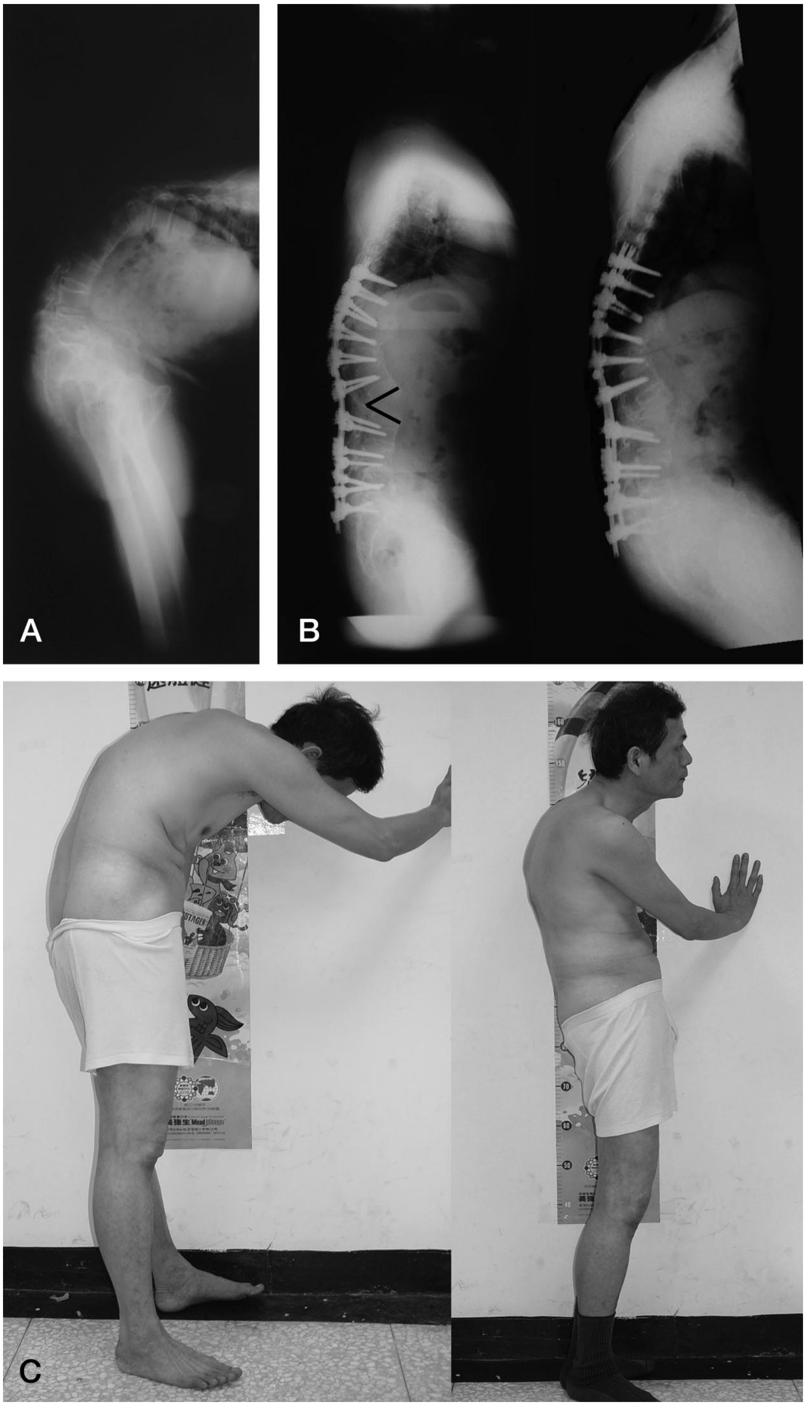

Figure 3. Images in a 48-year-old man with severe flexion deformity. **A,** Preoperative lateral radiograph. **B,** Postoperative lateral radiograph shows correction of the deformity with OWO at L2–3. The osteotomy resulted in solid fusion at 6 months after surgery. **C,** Preoperative and ultimate postoperative clinical appearance.

without adverse effect on the final result. No permanent neurologic deficits were directly referable to the osteotomy, but six cases had early postoperative deficits. One OWO patient was unable to empty his bladder 1 week after surgery, and five patients (two OWO, three CWO) had a weak quadriceps on one side. None of these neurologic deficits was predicted by the intraoperative somatosensory-evoked potentials. The deficits were detected by means of an intraoperative wake-up test in two patients, immediate postoperative examination in three, and urinary retention in the other patient 1 week after surgery. The patients ultimately responded to additional central canal enlargement and root decompression and recovered. Three OWO patients had nonunion and a broken rod at the osteotomy site; they underwent revision and healed uneventfully. Distal-screw loosening occurred in four patients (one OWO, three CWO) within 3 months of surgery. In one CWO patient, the screw was removed because of its prominence. The remainder required external immobilization for 6 months without further surgical intervention, with no evidence of progressive screw loosening at last follow-up. Five patients (two OWO, three CWO) had substantial kyphosis at segments proximal to the instrumented fusion. Three pa-

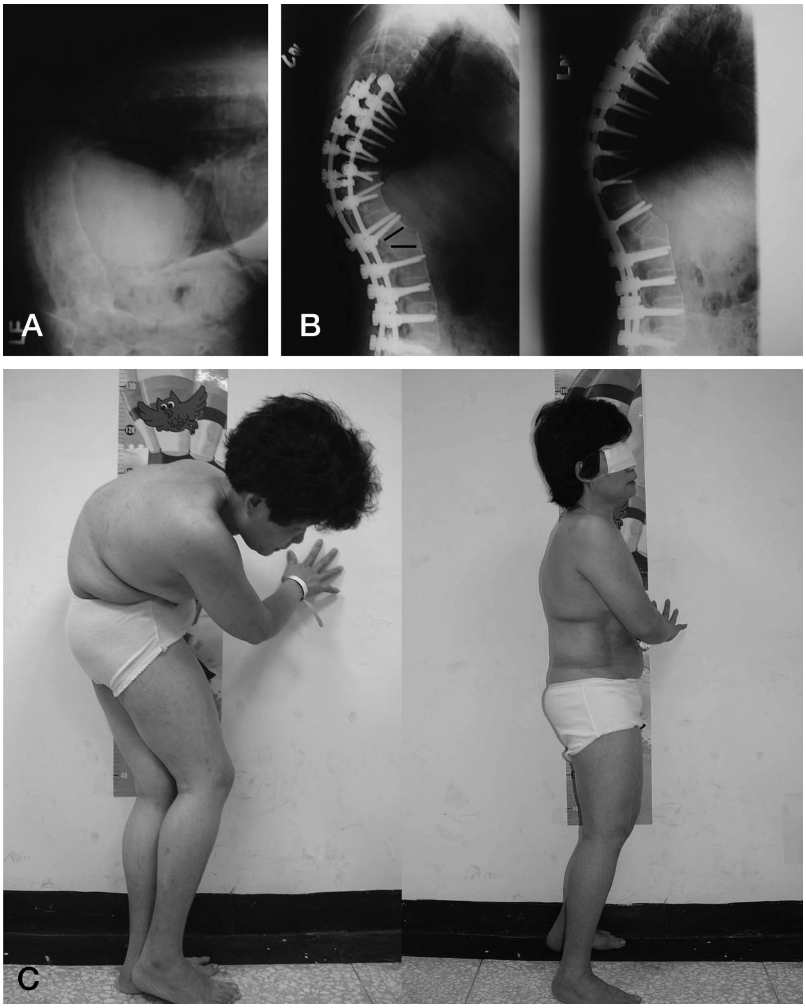

Figure 4. Images in a 44-year-old woman with severe flexion deformity. **A,** Preoperative lateral radiograph. **B,** Postoperative lateral radiograph shows correction of the deformity with CWO at L2. Correction exceeded the anatomic limitation of one vertebral body. The hinge was fractured to approximate the best possible sagittal balance. The osteotomy resulted in solid fusion at 4 months after surgery. **C,** Preoperative and ultimate postoperative clinical appearance.

tients presented at 3 months after surgery, and two presented at 6 months. All five required repeat operation at the segment with extension of the fusion and instrumentation into the upper thoracic spine (Figure 5).

SRS Outcomes Data

Table 5 shows the SRS questionnaire scores, and Table 6 summarizes the responses to questions 16 to 24. Fifty-eight OWO patients were extremely satisfied, and all would have the same treatment again. Forty-five CWO were extremely satisfied, and all would have the same management again. SRS outcome scores did not differ between the groups.

Table 2. Operation Time, Blood Loss, and Postoperative Ambulation

Operative Data	OWO (n = 66)	CWO (n = 51)
Operative time (mins)	182.6 ± 63.7 (162–241)	217.7 ± 61.6 (182–310)
Estimated blood loss (mL)	1101 ± 611.1 (900–1431)	1914.5 ± 718.9T(1110–3275)
Ambulation (days)		
Mean	4.5	4.9
Range	(3–7)	(2–6)
No. of osteotomy sites		
L1–L2	5	0
L2	0	47
L2–L3	55	0
L3	0	4
L2–L4	6	0

Note. Data are the mean or mean ± SD (range) unless otherwise noted.

Table 3. Radiographic Data

Radiographic Data	OWO (n = 66)	CWO (n = 51)
Thoracic kyphosis (°)		
Preop	57 ± 16 (48–67)	54 ± 13 (47–70)
Immediate postop	56 ± 15 (48–67)	55 ± 14 (46–72)
Final follow-up	59 ± 14 (49–70)	57 ± 11 (47–70)
Lumbar lordosis (°)		
Preop	−3 ± 11 (−25 to 10)	−5 ± 13 (−22 to 13)
Immediate postop	37 ± 13 (23–49)	33 ± 18 (23–41)
Final follow-up	34 ± 17 (21–43)	31 ± 16 (20–39)
Correction	40 ± 14 (20–68)	38 ± 11 (25–60)
Loss of correction	3 ± 4 (1−7)	2 ± 3 (0–8)
Sagittal plumb line (mm)		
Preop	141 ± 53 (93–271)	146 ± 64 (97–260)
Immediate postop	35 ± 8 (13–61)	47 ± 7 (17–61)
Final follow-up	61 ± 29 (27–78)	69 ± 41 (29–80)
Correction	106 ± 44 (41–211)	99 ± 33 (44–199)
Loss of correction	26 ± 8 (19–42)	22 ± 3 (18–38)

Note. Data are the mean ± SD (range).

Table 4. Complications

Complication	OWO (n = 66)	CWO (n = 51)
Dura laceration	4	3
Paralytic ileus	11	3
Pneumonia	2	1
Superficial infection	1	1
Transient radiculopathy	3	3
Nonunion/rod broken	3	0
Distal screw loosening	1	3
Adjacent segment kyphosis	2	3

Discussion

AS-related kyphotic deformity restricts psychosocial activities and physical functioning of many patients. Smith-Petersen *et al*[7] mentioned impairment of lower-extremity function, whereas Hehne *et al*[6] and Puschel and Zielke[24] reported pain, impairment of function, and social and professional disadvantages. Simmons[10] found that the degree of functional impairment is an important consideration for surgery. McMaster[8] reported that osteotomy might afford a better chance of returning to gainful employment and social acceptance, and Camargo *et al*[25] reported that improvement in appearance was of utmost psychological importance, improving mental attitudes and the ability and willingness to participate socially.

Smith-Petersen *et al*[7] originally preformed OWO in six patients in 1945. This technique involved two- and three-level osteotomies through the L1, L2, and L3 articular processes. Correction of kyphotic deformity was achieved by forceful manual extension of the lumbar spine to close the posterior wedge osteotomies. This manipulation disrupted the anterior longitudinal ligament, creating an anterior monosegmental intervertebral opening wedge with elongation of the anterior column. Modifications have been described.[1–3,8–12,26,27] Because the sharp lordotic angle and elongation of the anterior column were assumed to be associated with serious vascular and neurologic complications,[3,10,26–30] CWO was introduced.

Scudese[21] first described monosegmental lumbar CWO to correct AS-related kyphosis in 1962, followed by Ziwjan[31] and Thomasen.[15] In this technique, the posterior elements of one vertebra, including the lamina, articular processes, and pedicles, with the posterior wedge of the vertebral body, are resected. Correction is achieved by passive extension of the lumbar spine to close the posterior osteotomy with an anterior hinge. Internal fixation with wiring, metal plates, or transpedicular fixation has been used to ensure immediate stability and rapid consolidation.

At present the two techniques are used in AS-related kyphosis, and we attempted to offer a rationale for surgical decision-making based on outcomes. OWO is a limited osteotomy involving only the posterior element. Given the spinal fragility in AS, transvertebral osteotomy is not necessary to release the anterior structures. The anterior and middle columns are opened by manual osteoclasis rather than transvertebral osteotomy. The middle column should be hard enough to act as a hinge without collapsing during the pivotal corrective procedures. Therefore, we chose not to perform OWO in os-

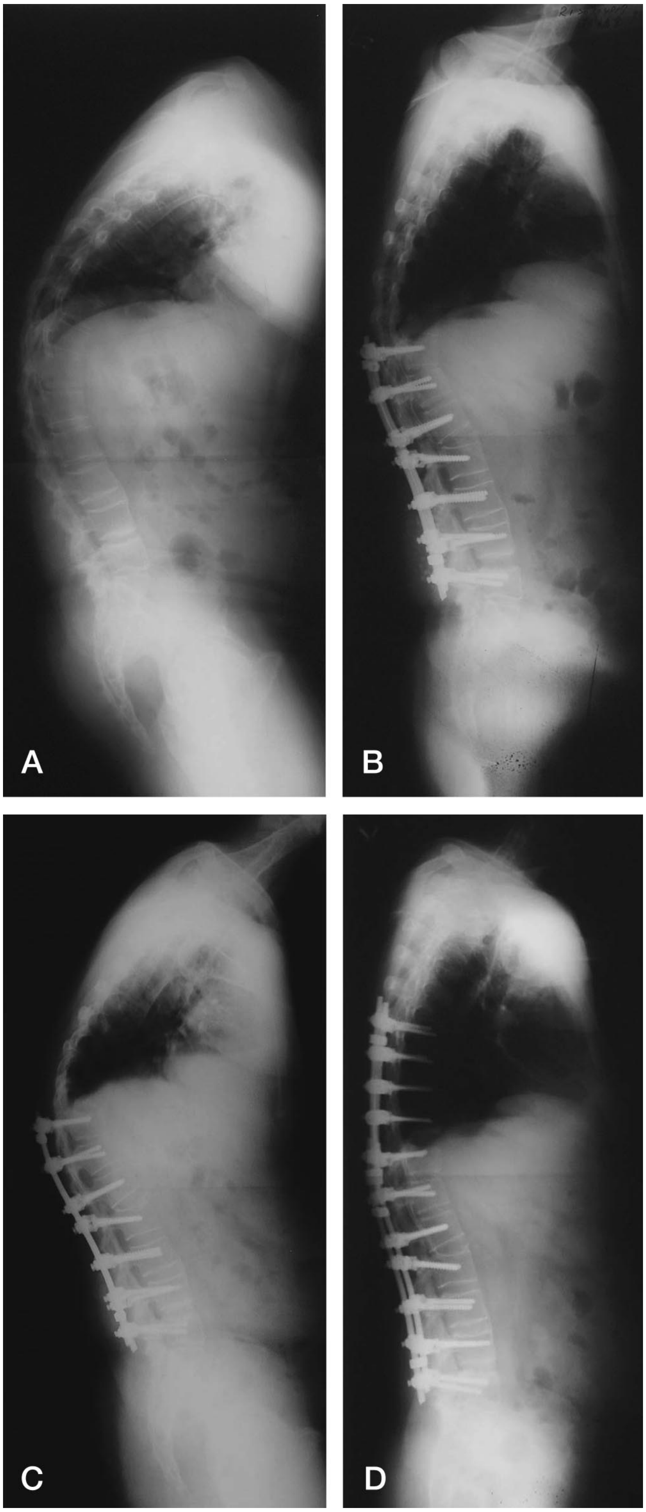

Figure 5. Images in a 40-year-old man with severe flexion deformity. **A,** Preoperative lateral radiograph. **B,** Postoperative lateral radiograph shows correction of the deformity with OWO at L1–2. **C,** Junctional kyphosis developed at the proximal segment. **D,** OWO and extension of the fusion and instrumentation into the upper thoracic spine was performed because of progression of the deformity.

Table 5. SRS Outcomes Data

SRS Average Scores	OWO	CWO
Questions 1–15 (maximum score = 75)	53.6	55.5
Questions 16–24 (maximum score = 45)	42.4	42.3

teoporotic patients. CWO involves three vertebral columns and achieves sagittal-plane correction by placing the hinge of correction anteriorly, shortening the spine, and avoiding an anterior opening in the anterior and middle columns. Compared with OWO, a posterior-base wedge osteotomy of the vertebral body, which includes resection of posterior and lateral wall and decancellation of a vertebral body, must be performed with CWO. These additional procedures are easier in osteoporotic patients; therefore, we preferred CWO in osteoporotic AS patients. Because CWO is more complicated than OWO, it increased operative time and blood loss.

Theoretically, OWO may have a larger correction than CWO, because maximum correction achieved with CWO technique is restricted by the anatomic limitations of one vertebral body. This showed to be about 35°.[32–35] However, there was no significant difference in the correction achieved in both groups. Correction as high as 60° can be achieved with CWO by fracturing the anterior hinge of the osteotomy (Figure 4). The corrective procedure aims for the best possible sagittal balance. During osteotomy, the patient's shoulder is raised to the same horizontal level as the pelvis, and the anterior cortex at the level of CWO is fractured at this position if correction attempted by closing the intravertebral osteotomy is not enough and if the anatomic limitations must be exceeded to approximate the best sagittal balance; this is especially the case if the bone is osteoporotic. Generally, correcting spinal deformity with CWO has been considered safe since Leatherman and Dickson's report.[32] However, many believe excessive shortening is dangerous and that a safety limit exists. Gertzbein and Harris[33] limited their corrections to approximately 30 to 40°. If kyphotic correction is >40° with CWO, the spinal cord may be too long for the shortened column. It may become curved or kinked or potentially damaged because the hinge is positioned at the anterior longitudinal ligament at the apex of the deformity. In their report on posterior transvertebral osteotomy, Lehmer *et al*[34] recommend that correction at any one level should not exceed approximately 35°. Describing transpedicular wedge resection osteotomy, Berven *et al*[35] recommend that correction of a sagittal deformity should be below

Table 6. SRS Postoperative Questions and Patients' Answers

Question		Total No. of Patients Answering Each Question				
16. Has your back treatment changed your function and daily activity?		Increased	Somewhat increased	Not changed	Somewhat decreased	Decreased
	OWO	38	17	11	0	0
	CWO	22	16	13	0	0
17. Has your back treatment changed your ability to enjoy sports/hobbies?		Increased	Somewhat increased	Not changed	Somewhat decreased	Decreased
	OWO	45	11	10	0	0
	CWO	29	13	9	0	0
18. Has your back treatment____________your back pain?		Increased	Somewhat increased	Not changed	Somewhat decreased	Decreased
	OWO	0	2	18	20	26
	CWO	0	2	8	12	29
19. Has your treatment changed your confidence in personal relationships with others?		Increased	Somewhat increased	Not changed	Somewhat decreased	Decreased
	OWO	60	6	0	0	0
	CWO	50	1	0	0	0
20. Has your treatment changed the way others view you?		Much better	Better	Same	Worse	Much worse
	OWO	57	9	0	0	0
	CWO	43	8	0	0	0
21. Has your treatment changed your self-image?		Increased	Somewhat increased	Not changed	Somewhat decreased	Decreased
	OWO	60	6	0	0	0
	CWO	45	6	0	0	0
22. Are you satisfied with the results of your back treatment?		Extremely satisfied	Somewhat satisfied	Neither satisfied nor dissatisfied	Somewhat dissatisfied	Extremely satisfied
	OWO	58	8	0	0	0
	CWO	45	6	0	0	0
23. Compared to before your treatment, how do you feel you now look?		Much better	Better	Same	Worse	Much worse
	OWO	60	6	0	0	0
	CWO	47	4	0	0	0
24. Would you have the same treatment again if you had the same condition?		Definitely yes	Probably yes	Not sure	Probably not	Decreased
	OWO	63	3	0	0	0
	CWO	49	2	0	0	0

L1 and of a magnitude correctable with a closing wedge of <45°. However, many CWO patients achieved correction of over 45° obtained without neurologic complications. This finding demonstrated the safety of this technique as well as the tolerance of cauda equina. Redundant cauda equina seems to cause no problems only if enough bone is removed to accommodate the excess tissue. CWO could be appropriate for correcting severe kyphotic to the same degree as OWO.

Theoretically, OWO can lack primary anterior stability. As a result, the posterior fusion zone and implants are under considerable tension, which increases the risk of implant failure, delayed union or nonunion, and inevitable loss of correction. However, the loss of lumbar-lordosis correction did not differ in our groups; this might have been attributable to the rapid union of the open wedge in AS patients. Most patients achieve solid fusion in 6 months, with good correction maintained at the osteotomy. We try to approximate the center of gravity of the upper body behind the OWO site to achieve the best sagittal balance, which helps to maintain correction. Three broken rods did occur at the osteotomy site because of delayed union after OWO but not CWO. All three patients had removed their TLSO and resumed their normal activities too early.

Sagittal balance significantly changed between the immediate postoperative period and last follow-up in both groups. During follow-up, satisfactory correction was maintained at the osteotomy site, but posture deteriorated in 13 patients because of increasing flexion deformity at other sites. Eleven patients required cervical osteotomy or total hip replacement to restore their posture, but these procedures resulted in correction loss in sagittal balance. McMaster and Coventry[2] followed up 17 patients for a mean of 10 years after lumbar osteotomy and found that once the osteotomy had fused, correction in the lumbar region was maintained. However, active disease in the thoracic and cervical spine or hips could allow for increased local deformity and detract from the initial correction. The correction was more persistent if osteotomy was done after the disease had resolved. Unfortunately, if the spinal deformity is already crippling, it is not possible to wait for the disease to become quiescent. However, correction lost at sites other than that of the lumbar osteotomy can often be improved with hip replacement or cervical osteotomy.

The incidence of paralytic ileus was higher with OWO than CWO and was assumed to be associated with elongation of lumbar spine, which might have caused tension on the anterior abdominal organs. This effect would be most pronounced in cases of long-standing spinal kyphosis deformity and contractures of the prevertebral tissue.

Rupture of the aorta or its branches is associated with reduced elasticity of the aorta wall in older patients and with the sharp lordotic angle and elongation of the anterior column. Generally accepted theories include stretch of calcific nondistensible and tethered vessels creating internal and media tears leading to rupture and aneurysms. Although this risk is small,[28–30] many surgeons choose CWO to avoid this complication. We believe the elasticity of aorta may be the most important factor in determining whether OWO would lead to aortic damage. In this study we excluded patients older than 50 years of age and those with atheromatous deposits and calcification in the aortic wall for OWO to minimize the risks of vascular complications. Vascular injury has been reported if the opening wedge was performed at L1-L2 or L2–L3.[36,37] Many series used OWO in which the spine is osteotomized through the posterior elements and corrected by direct pressure on the osteotomy site. The upper body and legs are extended to form a hollow cavity between the patient's ventral trunk and the surgical table, and the pressure causes the ossified anterior vertebral column to fracture. This often occurs with a sudden snap, which suddenly stretches the aorta opposite the anterior opening wedge and might injure the aorta. The osteoclasis created by this pressure might avulse a bone fragment from the vertebral body to form a spike, and the aorta may be tensed most at the spike while the anterior wedge is opened, which might lead to aortic damage. In our OWO patients, the osteoclasis usually occurred at the intervertebral disc at the level of osteotomy during performed posterior osteotomy by gravity on the patient's trunk or by light pressure on the osteotomy site after osteotomy. If the ossified anterior vertebral column was too hard to be fractured by light pressure, a fluoroscopically guided osteotome was placed through the intervertebral disc at the level of the osteotomy. Then, osteoclasis was formed by gentle manipulation. The osteoclasis thus formed occurs at anterior disc space. Correction should not be started without assured osteoclasis and is accomplished by a slow and finely controlled closure of the osteotomy. As the posterior wedge is closed, correction occurs in the anterior vertebral column by opening of the anterior disc space with smooth edges. All these managements for OWO were to minimize the risks of vascular complications and seemed effective because none of our OWO patients had a vascular injury.

Lumbar osteotomy poses a risk of neurologic complications, such as that attributable to displacement of a vertebral body. Dorsal nerve root compression can also be created by closure of the osteotomy. A nerve root can be nipped in the intervertebral canal when too little bone is removed. Six patients had neurologic deficits, which were limited to one side and not predicted with spinal cord monitoring. Two patients were predicted by intraoperative wake-up test. While doing intraoperative wake-up test, the patient was awakened and asked to follow the surgeon's order. The surgeon held the patient's leg and kept the patient's knee in flexed position. No active movement to extend the knee was observed or felt by the surgeon after his order was judged to have positive neurologic deficit to quadriceps. We examined the nerve root and indeed found nerve root compression created dorsally by closure of the osteotomy, then we performed additional central canal enlargement and root decompression. Immediate postoperative examination of the two patients showed a weak quadriceps on one side, but they ultimately responded to these managements and recovered. We believe the two patients had incomplete neurologic deficit according to our intraoperative observation and the ultimate response of the patients.

This finding emphasizes the importance of examining the nerve root during surgery and of performing wake-up tests afterward. We enlarge the canal centrally and pass a Woodson elevator up and down the canal through the area of central decompression to detect nerve root compression created dorsally by closure of the osteotomy. If we perform an osteotomy at L2, we resect the central arch of L2 and a portion of the central arch of L1 and L3 at minimum. In certain circumstances, we may resect some of the central arch of L4 as well. We strive to close down the lateral masses tightly at the end of the procedure, and we always perform wake-up tests after osteotomy closure.

Five junctional kyphoses developed at the segment proximal to the instrumented fusion (two OWO, three CWO). They progressed and required repeat OWO and extension of the fusion and instrumentation into the upper thoracic spine (Figure 5). A structural difference between the instrumented and noninstrumented segment of the AS spine might have increased stress at some of these junctions. In substantial thoracic kyphosis, the posterior elements are in tension, favoring the formation of progressive junctional kyphosis. Revision by reconstructing alignment was required to relieve these forces.

Functional outcomes and quality of life are important in kyphotic surgery, and most patients in both groups thought that their pain improved. Halm *et al*[18] reported that patients in both active phase and also the late phases of disease experienced pain relief, possibly the result of the spinal realignment. Most of our patients also experienced pain relief, though all were in the late phase. We also agree that spinal realignment affects outcomes.[6,18,20] Most patients in both groups reported improved self-image, function, and daily activities, and all patients would have the same treatment again. Outcome analysis showed no significant difference between the two groups. Because patients' satisfaction is related to improvements in physical appearance and psychosocial activities, few patients had poor outcomes. It is difficult to detect associations between objective measurements and subjective outcomes.

This study had a deficiency. We could not characterize how much osteoporosis the patient had to determine our decision on whether to do CWO *versus* OWO. We did formal radiologic evaluation with DEXA scans before surgery to investigate patients' bone density. However, it was used for reference only and not for decision-making, because sometimes the bone quality at the level of osteotomy diverged from the T value determined by DEXA scans. A AS patient with a diagnosis of osteoporosis according to T value ($T < -2.5$), still the bone at the level osteotomy might be quiet hard because Wolff's law of bony response to stress resulted from the kyphotic deformity, especially if it is near the apex of kyphosis. Besides, how much bone density at the level of osteotomy is enough for OWO has not been reported and standardized. We use rongeur to remove the lamina and pedicle at the level of osteotomy. We can assess the quality of bone by feeling how much the biting force of the rongeur is required to remove the bone and by using a curette to curette the cancellous bone within the pedicle to feel the hardness of the cancellous bone. The quality of bone at the level of osteotomy can thus be confirmed by intraoperative evaluation and feeling through using surgical tools. It is a vague concept of intraoperative judgment; however, this is a dependable method used at the author's institution to assess the quality of the bone at the level of osteotomy and to make a surgical decision.

The authors do not intend to make an argument that OWO is definitely better than CWO. The results of this study do not imply there is preference for one of the surgical techniques. This study showed no differences between the correction achieved by the two techniques. The technical outcome data showed that with the use of OWO, there is a tendency towards more complications such as postoperative ileus attributable to lengthening the anterior column and tension on the anterior abdominal organ, and delayed union with a broken rod attributable to lack of anterior stability. However, in comparison with OWO, a posterior-base wedge osteotomy of the vertebral body, which includes resection of posterior and lateral wall and decancellation of a vertebral body, must be performed with CWO, although it increased operative time and blood loss.

Another important issue of this study is that we attempt to offer a rationale for surgical decision-making based on outcomes. For OWO, the middle column should be hard enough to act as a hinge without collapsing during the pivotal corrective procedures. Therefore, we chose not to perform OWO in patients with poor bone quality at the level of osteotomy. If surgeons intend to performed OWO but this results in collapse of the middle column during corrective procedures, it might cause neurologic complications attributable to nerve compression by retropulsed bone from the collapsed middle column, and satisfactory correction might not be achieved. On the other hand, if the bone at the level of osteotomy was soft and osteoporotic, we performed CWO because intervertebral wedge osteotomy was easier. We did not consider OWO in patients older than 50 and in those with athermanous deposits and calcification in the aortic wall to minimize the risks of vascular complications. Both the radiographic and clinical outcomes demonstrate that these considerations for decision-making seem rational.

Key Points

- This study compared the results of closing wedge osteotomy (CWO; n = 51) and open wedge osteotomy (OWO; n = 66) in patients with kyphosis caused by ankylosing spondylitis.
- CWO was more complicated than OWO and resulted in significantly increased operating time and blood loss. However, OWO increased the likelihood of paralytic ileus and delayed union with a broken rod.
- CWO and OWO did not differ in the risk of neurologic and vascular complications, which can be avoided with strict attention to the details of the surgical procedure. Similarly, there was no difference in the correction of kyphosis.
- Both techniques had good clinical outcomes, improved the patients' quality of life, and resulted in high patient satisfaction.

References

1. Goel MK. Vertebral osteotomy for correction of fixed flexion deformity of the spine. *J Bone Joint Surg Am* 1968;50:287–94.
2. McMaster MJ, Coventry MB. Spinal osteotomy in ankylosing spondylitis: technique, complications, and long-term results. *Mayo Clin Proc* 1973;48: 476–87.
3. Adams JC. Technique, dangers and safeguards in osteotomy of the spine. *J Bone Joint Surg Br* 1952;34:226–32.
4. Dawson CW. Posterior elementectomy in ankylosing arthritis of the spine. *Clin Orthop* 1957;10:274–81.
5. Gerscovich EO, Greenspan A, Montesano PX. Treatment of kyphotic deformity in ankylosing spondylitis. *Orthopedics* 1994;17:335–42.
6. Hehne HJ, Zielke K, Bohm H. Polysegmental lumbar osteotomies and transpedicled fixation for correction of long-curved kyphotic deformity in ankylosing spondylitis: report on 177 cases. *Clin Orthop* 1990;258:49–55.
7. Smith-Petersen MN, Larson CB, Aufranc OE. Osteotomy of the spine for correction of fixation deformity in rheumatoid arthritis. *J Bone Joint Surg* 1945;27:1–11.
8. McMaster MJ. A technique for lumbar spinal osteotomy in ankylosing spondylitis. *J Bone Joint Surg Br* 1985;67:204–10.
9. Bossers GT. Columnotomy in severe Bechterew kyphosis. *Acta Orthop Belg* 1972;38:47–54.
10. Simmons EH. Kyphotic deformity of the spine in ankylosing spondylitis. *Clin Orthop* 1977;128:65–77.
11. Camargo FP, Corderio EN, Napodi MM. Corrective osteotomy of the spine in ankylosing spondylitis. Experience with 66 cases. *Clin Orthop* 1986;208: 157–67.
12. Weale AK, Marsh CH, Yeoman PM. Secure fixation of lumbar osteotomy. Surgical experience with 50 patients. *Clin Orthop* 1995;321:216–22.
13. Bradford DS, Schumacher WL, Lonstein JE, et al. Ankylosing spondylitis: experience in surgical management of 21 patients. *Spine* 1987;2:238–43. Erratum: *Spine* 1987;12:590–92.
14. Emneus H. Wedge osteotomy of spine in ankylosing spondylitis. *Acta Orthop Scand* 1968;39:321–6.
15. Thomasen E. Vertebral osteotomy for correction of kyphosis in ankylosing spondylitis. *Clin Orthop* 1985;194:142–51.
16. Van Royen BJ, Slot GH. Closing-wedge posterior osteotomy for ankylosing spondylitis. Partial corporectomy and transpedicular fixation in 22 cases. *J Bone Joint Surg Br* 1995;77:117–21.
17. Jaffray D, Becker V, Eisenstein S. Closing wedge osteotomy with transpedicular fixation in ankylosing spondylitis. *Clin Orthop* 1992;279:122–6.
18. Halm H, Metz-Stevenhagen P, Zielke K. Results of surgical correction of kyphotic deformities of the spine in ankylosing spondylitis on the basis of the modified arthritis impact measurement scales. *Spine* 1995;20:1612–9.
19. Thiranont N, Netrawichien P. Transpedicular decancellation closed wedge vertebral osteotomy for treatment of fixed flexion deformity of spine in ankylosing spondylitis. *Spine* 1993;18:2517–22.
20. Kim KT, Lee SE, Kim YW et al. Lumbar posterior wedge osteotomy of kyphotic deformity in ankylosing spondylitis. *J Korean Orthop Assoc* 1997; 32:1756–65.
21. Scudese VA, Calabro JJ. Vertebral wedge osteotomy. Correction of rheumatoid (ankylosing) spondylitis. *JAMA* 1963;186:627–31.
22. Asher MA, Min LS, Burton DC. Further development and validation of the scoliosis research society (SRS) outcomes instrument. *Spine* 2000;25: 2381–6.
23. Haher TR, Group JM, Shin TM, et al. Results of the Scoliosis Research Society instrument for evaluation of surgical outcomes in adolescent idiopathic scoliosis: a multicenter study of 244 patients. *Spine* 1999;24:1435–40.
24. Puschel J, Zielke K. Transpedicular vertebral instrumentation using VDS-instruments in ankylosing spondylitis. *Orthop Trans* 1985;9:130.
25. Camargo FP, Cordeiro EN, Napodi MM. Corrective osteotomy of the spine in ankylosing spondylitis: experience with 66 cases. *Clin Orthop* 1986;208: 157–167.
26. Law WA. Osteotomy of the spine. *Clin Orthop* 1969;66:70–6.
27. Styblo K, Bossers GT, Slot GH. Osteotomy for kyphosis in ankylosing spondylitis. *Acta Orthop Scand* 1985;56:294–7.
28. Klems VH, Friedebold G. Ruptur der Aorta abdominalis nach Aufrichtungsoperation bei Spondylitis ankylopoetica. *Z Orthop* 1971;108:554–63.
29. Weatherley C, Jaffary D, Terry A. Vascular complications associated with osteotomy in ankylosing spondylitis: a report of two cases. *Spine* 1988;13: 43–6.
30. Lichtblau PO, Wilson PhD. Possible mechanism of aorta rupture in orthopaedic correction of rheumatoid spondylitis. *J Bone Joint Surg Am* 1956;38: 123–7.
31. Ziwjan JL. Die behandlung der Flexionsdeformitaten der Wirbelsaule bei der Bechterewschen Erkrankung. *Beitr Orthop Traumatol* 1982;29:195–9.
32. Leatherman KD, Dickson RA. Two-staged corrective surgery for congenital deformities of the spine. *J Bone Joint Surg Br* 1979;61:324–8.
33. Gertzbein SD, Harris MB. Wedge osteotomy for the correction of posttraumatic kyphosis. *Spine* 1992;17:374–9.
34. Lehmer SM, Keppler L, Buscup RS, et al. Posterior transvertebral osteotomy for adult thoracolumbar kyphosis. *Spine* 1994;19:2060–7.
35. Berven SH, Deviren V, Smith JA, et al. Management of fixed sagittal plane deformities. *Spine* 2001;26:2036–43.
36. Simons EH. In: Rothman S, ed. *The Spine*. 4th ed. Vol. 2. Philadelphia, PA: Saunders, 1999;1320.
37. White AH, Schofferman JA. Spine Care: Operative Treatment. Vol. 2. St. Louis, MO: Mosby, 1995;1673–5.
38. Chang KW, Chen HC, Chen YY et al. Sagittal rotation in opening wedge osteotomy for the correction of thoracolumbar kyphosis deformity in ankylosing spondylitis. *Spine*, submitted.