Springer

Dear Author,

Here are the proofs of your article.

- You can submit your corrections **online**, via **e-mail** or by **fax**.
- For **online** submission please insert your corrections in the online correction form. Always indicate the line number to which the correction refers.
- You can also insert your corrections in the proof PDF and **email** the annotated PDF.
- For fax submission, please ensure that your corrections are clearly legible. Use a fine black pen and write the correction in the margin, not too close to the edge of the page.
- Remember to note the **journal title**, **article number**, and **your name** when sending your response via e-mail or fax.
- **Check** the metadata sheet to make sure that the header information, especially author names and the corresponding affiliations are correctly shown.
- **Check** the questions that may have arisen during copy editing and insert your answers/ corrections.
- **Check** that the text is complete and that all figures, tables and their legends are included. Also check the accuracy of special characters, equations, and electronic supplementary material if applicable. If necessary refer to the *Edited manuscript*.
- The publication of inaccurate data such as dosages and units can have serious consequences. Please take particular care that all such details are correct.
- Please **do not** make changes that involve only matters of style. We have generally introduced forms that follow the journal's style.
  Substantial changes in content, e.g., new results, corrected values, title and authorship are not allowed without the approval of the responsible editor. In such a case, please contact the Editorial Office and return his/her consent together with the proof.
- If we do not receive your corrections **within 48 hours**, we will send you a reminder.
- Your article will be published **Online First** approximately one week after receipt of your corrected proofs. This is the **official first publication** citable with the DOI. **Further changes are, therefore, not possible.**
- The **printed version** will follow in a forthcoming issue.

Please note

After online publication, subscribers (personal/institutional) to this journal will have access to the complete article via the DOI using the URL: http://dx.doi.org/[DOI].
If you would like to know when your article has been published online, take advantage of our free alert service. For registration and further information go to: http://www.springerlink.com.

Due to the electronic nature of the procedure, the manuscript and the original figures will only be returned to you on special request. When you return your corrections, please inform us if you would like to have these documents returned.

Metadata of the article that will be visualized in OnlineFirst

ArticleTitle	Pedicle subtraction osteotomy for rigid kyphosis of the dorsolumbar spine	
Article Sub-Title		
Article CopyRight	Springer-Verlag (This will be the copyright line in the final PDF)	
Journal Name	Archives of Orthopaedic and Trauma Surgery	

Corresponding Author	Family Name	**Gavaskar**
	Particle	
	Given Name	**Ashok S.**
	Suffix	
	Division	
	Organization	Parvathy Ortho Hospital
	Address	Door No. 63A/44, Gandhi Road, Gill Nagar, Choolaimedu, Chennai, Tamil Nadu, 600094, India
	Email	gavaskar.ortho@gmail.com
Author	Family Name	**Naveen Chowdary**
	Particle	
	Given Name	**T.**
	Suffix	
	Division	
	Organization	Global Hospital
	Address	Door No. 115, Gill Nagar Extension, Choolaimedu, Chennai, Tamil Nadu, 600094, India
	Email	

	Received	14 June 2010
Schedule	Revised	
	Accepted	

Abstract	*Method:* Pedicle subtraction osteotomy is one of the well established and popular techniques for kyphosis correction. 52 patients with dorsolumbar kyphosis followed up for a minimum period of 2 years after pedicle subtraction osteotomy were assessed prospectively for clinico-radiological and functional outcomes. Unacceptable cosmesis and severe back pain were the chief complaints preoperatively. *Results:* The average kyphosis at last follow-up was 8.4° compared to preoperative kyphosis of 58°. Union at the osteotomy site was achieved in all patients, and there were no major neurological complications. All patients showed a significant improvement in all subsets of Scoliosis Research Society (SRS-30) outcome measures following the surgery. *Conclusion:* A greater degree of kyphosis correction (>40°) can be obtained with a single pedicle subtraction osteotomy at the dorsolumbar level with minimal neurological complications.

Keywords (separated by '-')	Spinal osteotomy - Kyphosis - Spinal deformity - Pedicle subtraction
Footnote Information	

Journal: 402
Article: 1224

Author Query Form

Please ensure you fill out your response to the queries raised below and return this form along with your corrections

Dear Author

During the process of typesetting your article, the following queries have arisen. Please check your typeset proof carefully against the queries listed below and mark the necessary changes either directly on the proof/online grid or in the 'Author's response' area provided below

Query	Details required	Author's response
1.	Please check and confirm the author names and initials are correct. Also, kindly confirm the details in the metadata are correct.	
2.	Please note that we have called Graphs 1 and 2 as Figs. 3 and 4, respectively, as per journal style.	
3.	Please check and confirm Ref. [4].	

Arch Orthop Trauma Surg
DOI 10.1007/s00402-010-1224-y

ORTHOPAEDIC SURGERY

Pedicle subtraction osteotomy for rigid kyphosis of the dorsolumbar spine

Ashok S. Gavaskar · T. Naveen Chowdary

Received: 14 June 2010

Abstract

Method Pedicle subtraction osteotomy is one of the well established and popular techniques for kyphosis correction. 52 patients with dorsolumbar kyphosis followed up for a minimum period of 2 years after pedicle subtraction osteotomy were assessed prospectively for clinico-radiological and functional outcomes. Unacceptable cosmesis and severe back pain were the chief complaints preoperatively.

Results The average kyphosis at last follow-up was 8.4° compared to preoperative kyphosis of 58°. Union at the osteotomy site was achieved in all patients, and there were no major neurological complications. All patients showed a significant improvement in all subsets of Scoliosis Research Society (SRS-30) outcome measures following the surgery.

Conclusion A greater degree of kyphosis correction (>40°) can be obtained with a single pedicle subtraction osteotomy at the dorsolumbar level with minimal neurological complications.

Keywords Spinal osteotomy · Kyphosis · Spinal deformity · Pedicle subtraction

A. S. Gavaskar (✉)
Parvathy Ortho Hospital, Door No. 63A/44,
Gandhi Road, Gill Nagar, Choolaimedu,
Chennai 600094, Tamil Nadu, India
e-mail: gavaskar.ortho@gmail.com

T. Naveen Chowdary
Global Hospital, Door No. 115, Gill Nagar Extension,
Choolaimedu, Chennai 600094, Tamil Nadu, India

Introduction

An abnormal kyphotic spine can result in a positive sagittal imbalance that may have deleterious effects on the overall biomechanics of the spinal column. Loss of sagittal balance can cause intractable back pain due to abnormal posture and can cause lower limb muscle fatigue and inability to maintain a horizontal gaze. Kyphosis correction in the spine is a massive undertaking and requires careful preoperative clinical, radiological evaluation and immense technical expertise on the part of the surgeon.

Various surgical techniques are described in literature for kyphosis correction. Pedicle subtraction osteotomy (PSO) is a posterior closing wedge osteotomy first described by Thomasen [1] in 1985 for the management of fixed sagittal plane deformities in ankylosing spondylitis. Since then its indications have grown, and techniques have been modified to treat kyphotic deformities of the dorsolumbar and lumbar spine due to tuberculosis, trauma, degenerative and postsurgical conditions [2, 3]. PSO can be used at the dorsal level but at the expense of increased neurological complications. PSO is most useful for deformities with an apex in the lumbar spine [4].

We present our experience with the PSO for surgical correction of dorsolumbar kyphosis. Our aim was to correct the deformity and relieve back pain by restoring the normal spinal curvatures and achieving a solid fusion.

Patients and methods

The study cohort included 56 patients who underwent PSO for dorsolumbar kyphosis at our institution from January 2006 to December 2007. Prior informed consent and approval from the institutional ethical committee was

Large 402	1224	xxxx	Dispatch: 22.11.10	No . of Pages: 6
Journal	Article	MS Code	LE ☐ TYPESET ☐ CP ☑ DISK ☑	

obtained. Four patients were lost during follow-up, one patient had died due to reasons unknown, and three patients could not be traced. 52 patients were included for final analysis.

There were 31 males and 21 females. The average age was 25 years (range 18–33 years). The etiology of the deformity varied, 22 patients had healed tuberculosis of the dorsolumbar or lumbar spine, 15 patients had an unacceptable kyphotic deformity following Schuermann's disease of the dorsolumbar spine, 7 patients had a posttraumatic sharp kyphosis, and 8 patients presented with congenital kyphosis. All patients presented with a cosmetically unacceptable deformity and intractable back pain not responding to regular use of analgesics and bracing as their chief complaints. Eight patients complained of lower limb fatigue, but there were no neurological deficits on preoperative clinical evaluation.

All patients with healed tuberculosis had undergone a complete course of antituberculous chemotherapy for a minimum period of 12 months and were considered cured for a minimum period of 2 years after the completion of drug therapy. These patients on admission were assessed for disease activity. Clinical, serological (erythrocyte sedimentation ratio and C-reactive protein values) and radiological evaluations proved negative for active disease.

Preoperative pain and disability assessment was done using the SRS-30 outcome questionnaire. Preoperative standing AP and lateral X-rays were taken as part of the initial evaluation to assess the global and regional alignments of the spine. The preoperative lateral image was used to template the wedge resection at the planned osteotomy level. Flexion–extension radiographs were taken to assess the mobility of the spine above and below the osteotomy. The kyphotic deformity was measured on the lateral X-ray using the Konstam angle. Magnetic resonance imaging was done in all patients before contemplating surgery to evaluate the cord status, canal dimensions and nerve root compression. We also looked specifically for residual abscesses and reconstitution of end plates in patients with posttubercular kyphosis.

Wedge measurement and prediction of correction

All osteotomies were planned at the level of lumbar spine or at the dorsolumbar junction. The osteotomy in cases of posttubercular kyphosis was done at the level of the internal gibbus. The lumbar spine normally has 30° more lordosis than thoracic kyphosis. These considerations were kept in mind in planning the deformity correction. A tracing of the deformity was done on the lateral X-ray including three segments above and below the osteotomy. The transpedicular wedge resection will leave the height of the anterior column intact, but the posterior column will be compressed as a wedge, the height of which equals the height of the planned resection. Approximation of the tracing after wedge resection gives the amount of sagittal plane correction that will be achieved after the osteotomy. An additional osteotomy may be planned if more sagittal plane correction is needed.

Surgical technique

All patients were operated prone under general anesthesia with the operating table flexed to accommodate the deformity. All patients were catheterized before surgery to decrease intra-abdominal pressure. A hemostatic cocktail (around 250–300 mm) containing a combination of normal saline, sodium bicarbonate, lignocaine, hyalase and adrenaline was injected extensively at the surgical field to minimize surgical bleeding during exposure.

Exposure and instrumentation

A standard posterior midline incision was used. Instrumentation spanning a minimum of two levels above and below the osteotomy site was planned preoperatively, but the number of levels to be instrumented and the number of osteotomies were left to the discretion of the operating surgeon. After exposing the intended levels of instrumentation bilaterally, pedicle screws were inserted on both sides (uniaxial, stainless steel screws, Jayon Surgicals, India). After insertion of all screws, the position of screws was checked under image intensifier, and necessary modifications if any required were carried out. An appropriately contoured Moss-miami rod was applied on one side under slight distraction to prevent the spine from becoming unstable.

Pedicle subtraction

Complete laminectomy and facetectomy is done at the level of the osteotomy, and decompression is extended laterally to get access to the lateral walls of the vertebral body. After removal of the posterior elements, the remaining pedicle and nerve roots above and below are visible. Nerve roots should be carefully protected during the osteotomy. Decancellation is done through the pedicle on both sides with hand-held curettes. The lateral walls on both sides are osteotomized with the apex just posterior to the anterior cortex. Bleeding from the bone is controlled with the use of bone wax. The posterior wall under the thecal sac is removed with a Kerrison rongeur.

Wedge closure

Wedge closure is done by creating a green stick fracture through the anterior cortex. This is facilitated by reversal of

Large 402	1224	xxxx	Dispatch: 22.11.10	No . of Pages: 6
Journal	Article	MS Code	LE ☐ TYPESET ☐	CP ☑ DISK ☑

flexion in the operating table and applying compression posteriorly using the rod–screw construct. After closure of the osteotomy, the thecal sac is reassessed for compression, and the foraminal patency is checked. Local bone obtained during the process of decompression is used to augment fusion. The surgical wound is packed using gel foam and closed using a suction drain.

Postoperative management

Patients were mobilized early by second postoperative day after drain removal. Walking was allowed after the acute phase using a dorsolumbosacral orthosis for a period of 12–14 weeks. Follow-ups were made at 6 weeks, 12 weeks, 6 months and 1 year and 2 years before the final follow-up. At follow-up visits, X-rays (standing AP and dynamic) were taken to assess fusion, degree of deformity correction and loss of correction over time. Postoperatively patients completed self administered SRS-30 questionnaire at 6 months, 1 year and 2 years to assess the functional improvement. Clinico-radiological and functional evaluation done at 6 months, 1 year and 2 years were used to statistically assess and interpret the outcome trends following surgery. All data were collected and analyzed in a prospective manner. The mean follow-up was 31 months (range 24–48 months).

Statistical analysis

The SRS-30 subset scores for pain, function, self image and mental health obtained preoperatively, 6 months, 1 year and 2 years were analyzed using the stata (stata-11) statistics package. Paired *T* test was used to find out the level of statistical significance (p value < 0.05 was taken as significant) between the values in contiguous time frames.

Results

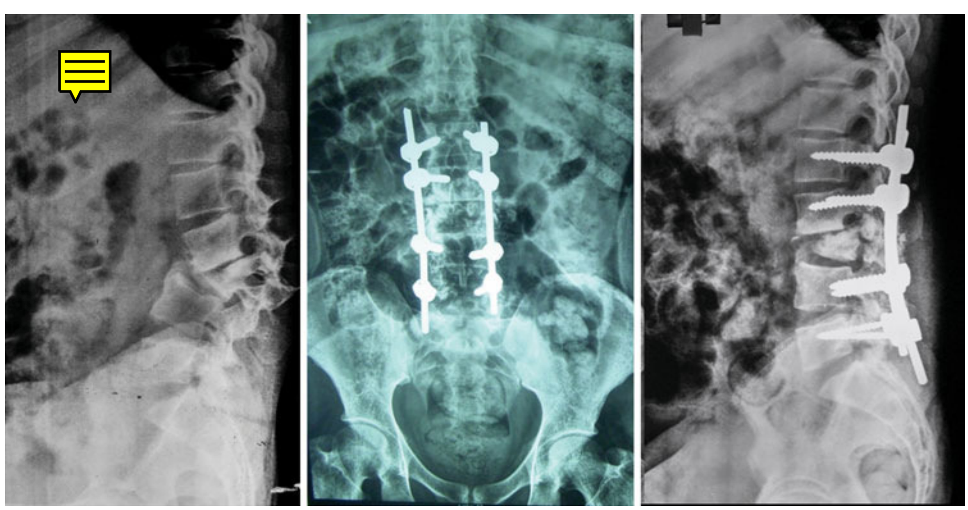
Perioperative data

The mean surgical time was 160 min (140–205 min). Only a single PSO was performed in all patients. The level of the osteotomy in our study ranged from D12 vertebra to the L3 vertebra. A minimum of four levels and a maximum of six levels were instrumented during the process of deformity correction. A total of 449 pedicle screws were inserted. The average blood loss was 1,100 ml (900–1,700 ml). All patients required at least a single unit of whole blood transfusion intraoperatively and another unit transfused after surgery. There were no major neurological complications. Three patients had a small dural tear which was not repaired. Transient weakness and sensory disturbance in the distribution of L2 and L3 roots were seen in six patients but recovered completely. No systemic complications were seen in the immediate postoperative period. Superficial wound infection was seen in two patients (Figs. 1, 2, 3).

Radiographic evaluation

Radiological evidence of fusion was seen in all patients (Figs. 1, 2, 3). Evidence of bridging trabeculae, absence of motion on dynamic radiographs was taken as conclusive evidence of fusion. There were no incidences of major hardware failure at last follow-up. Pedicle screw pull out (>5 mm) was seen in 27 of the 449 screws. 11 pedicle screws in ten patients were found broken between 6 months and 1 year following surgery, but the overall stability of the construct was maintained. Successful fusion took place uneventfully in these patients, and the loss of correction at final follow-up was not significant. The average preoperative Konstam angle was 58° (40°–90°). The mean Konstam angle immediately after surgery was 5° (0°–12°). The average

Fig. 1 Lumbar kyphotic deformity in a 24-year-old male patient due to tuberculous destruction of the L3 vertebra. Postoperative radiographs showing a solid fusion at the osteotomy site and good correction of the deformity



Large 402 Journal | 1224 Article | xxxx MS Code | Dispatch: 22.11.10 | No . of Pages: 6 | LE ☐ TYPESET ☐ CP ☑ DISK ☑

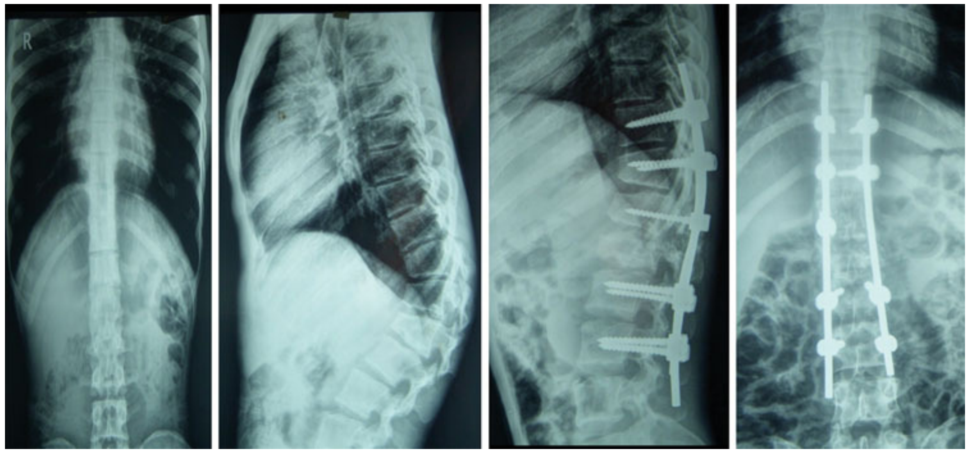


Fig. 2 Schuerman's kyphosis of the dorsolumbar spine in a 24-year-old male patient. Postoperative X-rays showing a satisfactory correction

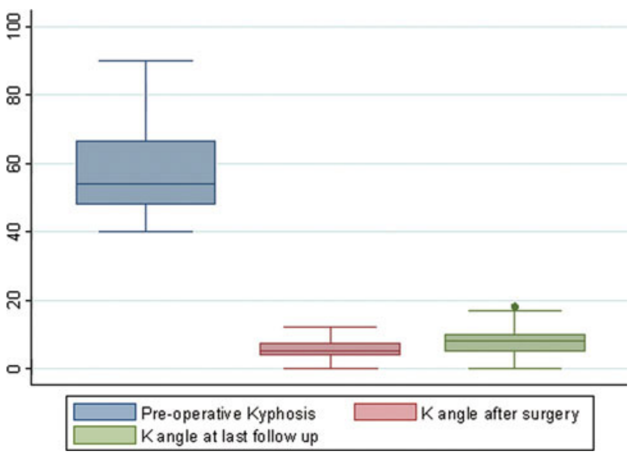


Fig. 3 Box plot depicting the amount of preoperative kyphosis and the subsequent kyphotic angles immediately after surgery and at final follow-up

K angle at ultimate follow-up (minimum 2 years) was 8.4° (0°–18°). The average final correction was 49.5° with a mean correction loss of 3.4° (0°–8°) (Fig. 4).

SRS-30 scores analysis

There was a significant improvement in all SRS subsets at 6 months compared to baseline values obtained before surgery (Fig. 4). Patients continued to show significant improvement in pain at 1 and 2 years compared to the values at 6 months and 1 year. A similar trend was seen in functional assessment and self image subset at 1 year compared to 6 months but plateaued thereafter. The mental health subset failed to show any further significant improvement after 6 months.

Discussion

A kyphotic spine results in an abnormal load transmission across the spinal column resulting in abnormal posture and back pain. Kyphosis correction in these patients can be achieved in a single sitting using posterior osteotomies. Smith–Peterson osteotomy, Pedicle subtraction osteotomy and the opening–closing osteotomy have been described and used successfully for kyphosis correction.

The Smith–Peterson [5] osteotomy originally described for ankylosing spondylitis involves multiple level posterior osteotomies since the correction achieved at a single segment is around 10°–15° [6]. This results in acute opening and lengthening of the shortened anterior column in long standing kyphosis. Acute lengthening of the anterior column can stretch the major vessels and the viscera anteriorly, and fatal complications have been reported [7, 8]. Opening of the anterior column and persistent distraction anteriorly can also make arthrodesis less reliable and may increase the incidence of pseudoarthrosis [9].

The PSO is a posterior closing wedge osteotomy with three column opposition. It can achieve a larger degree of correction at a single level, and the rates of pseudoarthrosis are minimal. Osteotomy through the bleeding cancellous bone surfaces and closure of the osteotomy using strong posterior transpedicular instrumentation produces close three column opposition of bone surfaces resulting in high rates of solid fusion. We achieved fusion at the osteotomy site in all patients. Similar results on high fusion rate have been reported by many authors after PSO [10, 11].

Blood loss during the procedure has been expressed as a cause of concern with average losses amounting as high as 2 l in some series [4, 6]. The average blood loss in our patients was much lesser probably because of the hemostatic mixture we had used. The blood loss as a result of surgical exposure was very minimal, and majority of the bleeding was from the raw bony surfaces. Epidural bleeding was controlled by bipolar cautery. It is vital to maintain adequate blood supply to spinal cord, and a competent anesthetic team to handle complications is necessary. Increased blood loss increases rate of complications and the transfusion rate.

Large 402 | 1224 | xxxx | Dispatch: 22.11.10 | No . of Pages: 6
Journal | Article | MS Code | LE ☐ TYPESET ☐ CP ☑ DISK ☑

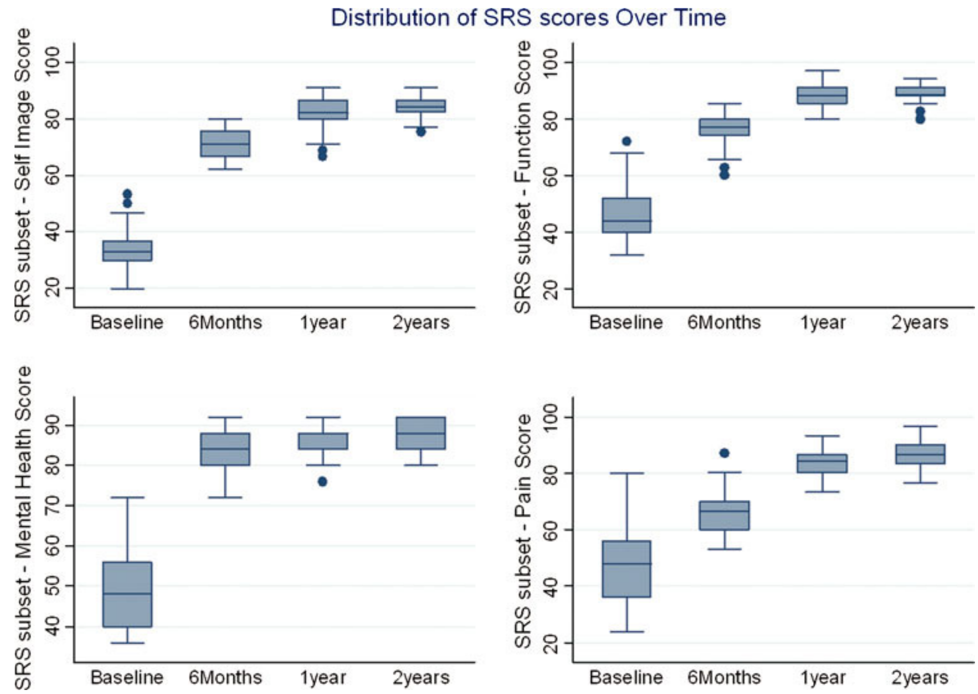


Fig. 4 Box plot showing the outcome trends using the SRS scores following PSO over 2-year follow-up

The PSO has been reported to achieve an average correction of 40° at a single segment [12, 13]. We achieved as much as 80° correction with a single osteotomy in a patient with tuberculosis. The degree of correction depends on the width of the base of the osteotomy and the distance of the apex from the base. More anterior the apex and more the width of the base allow more time for the cord to kink and thereby achieve a greater degree of correction without compromising the integrity of the spinal cord.

Incidence of neurological deficits has been reported to be high after PSO [14–16]. Neurologic deficits after PSO are due to spinal subluxation, dural kink and central canal compromise. Wake up test described by Stagnara and intraoperative neurological monitoring has been used in various studies to predict and prevent iatrogenic deficits. In a long-term study by Buchowski et al. [17], they found that neurologic monitoring did not predict any of the neurological deficits in their series. We did not use any type of intraoperative monitoring, but we stopped closing the osteotomy once the dura started to buckle. Forceful closure of the posterior osteotomy after pedicle subtraction increases the propensity for neurological deficits.

Nerve root deficits following PSO have been reported although PSO provides a larger neural foramen after removal of the pedicles. It has been shown that the isolated root deficits are due to compression in the central canal and the lateral recess rather than in the neural foramen. We had isolated transient root deficits in six patients (11.5%) which recovered completely. Buchowski [17] reported transient nerve root deficits in 11.1% and permanent deficits in 2.8% of his patients. Similar results were reported by Bridwell et al. [18] and Kim et al. [19], in 15.2 and 11.1%, respectively, of their patients who had temporary nerve root deficits. Our study shows a similar trend without the use of any sort of neurologic monitoring, but the volume of patients is small to draw any definitive conclusions.

The study has its own limitations; the etiologies were different, and the overall sagittal and coronal balances were not measured. The merits of the study are that all data were collected prospectively, and all surgeries were performed by surgeons with considerable experience in spinal deformity surgery. The outcome at the minimum 2-year follow-up suggests that the patients have significantly benefitted from the procedure.

Conflict of interest None.

References

1. Thomasen E (1985) Vertebral osteotomy for correction of kyphosis in ankylosing spondylitis. Clin Orthop Relat Res 194:142–152
2. Bridwell KH, Lewis SJ, Rinella A, Lenke LG, Baldus C, Blanke K (2004) Pedicle subtraction osteotomy for the treatment of fixed sagittal imbalance. Surgical technique. JBJS 86A(Suppl 1):44–50
3. Berven SH, Deviren V, Smith J, Emani A, Hu SS, Bradford DS (2001) Management of fixed sagittal plane deformity: results of the transpedicular wedge resection osteotomy. Spine 26:2036–2043
4. Wang MY, Berven SH (2007) Lumbar pedicle subtraction osteotomy. Neurosurgery 60(2 Suppl 1):ONS140–ONS146
5. Smith-Peterson M, Larson C, Aufranc O (1945) Osteotomy of the spine for correction of flexion deformity in rheumatoid arthritis. J Bone Joint Surg Am 27:1–11

Large 402	1224	xxxx	Dispatch: 22.11.10	No . of Pages: 6
Journal	Article	MS Code	LE ☐ TYPESET ☐ CP ☑ DISK ☑	

6. Cho KJ, Bridwell KH, Lenke LG, Berra A, Baldus C (2005) Comparison of Smith-Petersen versus pedicle subtraction osteotomy for the correction of fixed sagittal imbalance. Spine 30:2030–2037
7. Weatherly C, Jaffray D, Terry A (1988) Vascular complications associated with osteotomy in ankylosing spondylitis: a report of two cases. Spine 13:43
8. Adams JC (1952) Technique, dangers and safeguards in osteotomy of the spine. J Bone Joint Surg Br 34:226–232
9. Bridwell KH, Lenke LG, Lewis SJ (2001) Treatment of spinal stenosis and fixed sagittal imbalance. Clin Orthop 384:35–44
10. Jaffray D, Becker V, Eisenstein S (1992) Closing wedge osteotomy with transpedicular fixation in ankylosing spondylitis. Clin Orthop 279:122–126
11. Van Royen BJ, DeGast A (1999) Lumbar osteotomy for correction of thoracolumbar kyphotic deformity in ankylosing spondylitis: a structured review of three methods of treatment. Ann Rheum Dis 58:399–406
12. Thiranont N, Netrawichien P (1993) Transpedicular decancellation closed wedge vertebral osteotomy for treatment of fixed flexion deformity of spine in ankylosing spondylitis. Spine 18:2517–2522
13. Van Royen BJ, Slot GH (1995) Closing-wedge posterior osteotomy for ankylosing spondylitis: partial corpectomy and transpedicular fixation in 22 cases. J Bone Joint Surg Br 77:117–121
14. Yang BP, Ondra SL, Chen LA et al (2006) Clinical and radiographic outcomes of thoracic and lumbar pedicle subtraction osteotomy for fixed sagittal imbalance. J Neurosurg Spine 5:9–17
15. Ahn UM, Ahn NU, Buchowski JM et al (2002) Functional outcome and radiographic correction after spinal osteotomy. Spine 27:1303–1311
16. Murrey DB, Brigham CD, Kiebzak GM et al (2002) Transpedicular decompression and pedicle subtraction osteotomy (eggshell procedure): a retrospective review of 59 patients. Spine 27:2338–2345
17. Buchowski JM, Bridwell KH, Lenke LG, Kuhns CA, Lehman RA Jr, Kim YJ, Stewart D, Baldus C (2007) Neurologic complications of lumbar pedicle subtraction osteotomy: a 10-year assessment. Spine 2007; 32: 2245–2252
18. Bridwell KH, Lewis SJ, Edwards C et al (2003) Complications and outcomes of pedicle subtraction osteotomies for fixed sagittal imbalance. Spine 28:2093–2101
19. Kim KT, Suk KS, Cho YJ et al (2002) Clinical outcome results of pedicle subtraction osteotomy in ankylosing spondylitis with kyphotic deformity. Spine 27:612–618

Large 402	1224	xxxx	Dispatch: 22.11.10	No . of Pages: 6
Journal	Article	MS Code	LE ☐ TYPESET ☐	CP ☑ DISK ☑