Staged Correction of Severe Thoracic Kyphosis in Patients with Multilevel Osteoporotic Vertebral Compression Fractures

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Abstract

Study Design Technical report.

Objective Multilevel osteoporotic vertebral compression fractures may lead to considerable thoracic deformity and sagittal imbalance, which may necessitate surgical intervention. Correction of advanced thoracic kyphosis in patients with severe osteoporosis remains challenging, with a high rate of failure. This study describes a surgical technique of staged vertebral augmentation with osteotomies for the treatment of advanced thoracic kyphosis in patients with osteoporotic multilevel vertebral compression fractures.

Methods Five patients (average age 62 ± 6 years) with multilevel osteoporotic vertebral compression fractures and severe symptomatic thoracic kyphosis underwent staged vertebral augmentation and surgical correction of their sagittal deformity. Clinical and radiographic outcomes were assessed retrospectively at a mean postoperative follow-up of 34 months.

Results Patients' self-reported back pain decreased from 7.2 ± 0.8 to 3.0 ± 0.7 (0 to 10 numerical scale; $p < 0.001$). Patients' back-related disability decreased from 60 ± 10% to 29 ± 10% (0 to 100% Oswestry Disability Index; $p < 0.001$). Thoracic kyphosis was corrected from 89 ± 5 degrees to 40 ± 4 degrees ($p < 0.001$), and the sagittal vertical axis was corrected from 112 ± 83 mm to 38 ± 23 mm ($p = 0.058$). One patient had cement leakage without subsequent neurologic deficit. Decreased blood pressure was observed in another patient during the cement injection. No correction loss, hardware failure, or neurologic deficiency was seen in the other patients.

Conclusion The surgical technique described here, despite its complexity, may offer a safe and effective method for the treatment of advanced thoracic kyphosis in patients with osteoporotic multilevel vertebral compression fractures.

Keywords
- thoracic kyphosis
- severe osteoporosis
- osteoporotic fractures
- deformity correction
- staged procedure

Introduction

Vertebral compression fractures are frequent in patients with osteoporosis. The estimated occurrence is 15% in females and 5% in males of Caucasian origin.[1,2] The thoracolumbar and midthoracic vertebrae are the most commonly involved vertebrae, causing a loss of lumbar lordosis and/or increased thoracic kyphosis, leading to positive sagittal balance.[1–3] Frequent sequelae are back pain, early muscle fatigue, ambulation difficulty, and substantial decrease in quality of life.[1,4,5]

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Conservative treatment includes immobilization, analgesia, and physiotherapy as well as antiresorptive and anabolic medications, which may reduce the risk of future fractures and kyphosis progression.[6,7] If conservative treatment fails, unhealed fractures can be managed surgically by performing percutaneous vertebral cement augmentation. Cement injection may restore vertebral height and provide rapid analgesia and functional improvement.[8–13] However, in the case of multiple healed (old) osteoporotic fractures with established kyphotic deformity and sagittal imbalance, more extensive intervention may be indicated.

Several surgical techniques have been described for the correction of symptomatic sagittal imbalance in patients with osteoporosis.[12–14] These techniques usually involve lumbar subtraction osteotomy with fusion of the construct to the S1 and the pelvis.[15,16] Although effective in restoring sagittal balance, spinal pelvic fusion is associated with a high failure rate and the loss of movement in all the lumbar motion segments.[17] Moreover, the correction of the sagittal balance alone by lumbar osteotomy does not address the cosmetically disturbing thoracic hump. Because pedicle screw loosening and adjacent-level vertebral body fracture are common among patients with osteoporosis, surgeons tend to avoid correction of these challenging cases.[18–23]

This study presents our staged surgical correction technique and preliminary outcomes in a group of patients whose life quality was severely affected by their thoracic deformity and sagittal imbalance as a result of their multilevel osteoporotic vertebral compression fractures.

Materials and Methods

Patient Population

Five patients (two women and three men, average age 62 ± 6 years) with multiple osteoporotic vertebral compression fractures (four or five levels involved) and severe symptomatic thoracic kyphosis (an average kyphosis of 89 ± 5 degrees) underwent staged surgical correction of their spinal deformity, and results were reviewed at a mean of 34 ± 5 months (►**Table 1**). The study was conducted as a retrospective case series and as such, Institutional Review Board approval was not needed. The indications for surgery were back pain with severe thoracic deformity causing sagittal imbalance and related disability (difficulty in ambulation and in activities of daily living) and evidence of kyphosis progression due to new osteoporotic fractures seen on consecutive radiographs. For all patients, pain and disability did not diminish with nonoperative treatment over a period of at least 12 months. None had a neurologic deficit. All had severe osteoporosis (an average T-score of −3.2 ± 0.3, range −2.8 to −3.6) secondary to long-standing corticosteroid use, which was prescribed as an adjunct to chemotherapy for two patients with multiple myeloma and as immunotherapy for three patients (two with rheumatoid arthritis and one with inflammatory bowel disease). The preoperative assessment included a detailed physical examination, dual-energy X-ray absorptiometry scan for bone density measurement, standing unsupported anteroposterior and lateral radiographs of the whole spine and pelvis (for assessment of sagittal balance parameters), and magnetic resonance imaging of the whole spine (►**Fig. 1**).

Surgical Considerations

Preoperative planning was performed using whole-spine unsupported standing radiographs and magnetic resonance imaging. Multiple chevron osteotomies around the apex vertebra were planned based on deformity shape and the amount of sagittal balance correction required, assuming correction of ∼5 to 8 degrees per osteotomy.[24] In the cases of vertebral collapse with a sharp thoracic kyphotic angle, a pedicle subtraction osteotomy (PSO) without vertebral body augmentation was planned.[24] To minimize the risk of failure in the osteoporotic spine, the fusion included at least three levels above and below the last osteotomized vertebrae to avoid ending the instrumentation at or near a kyphotic segment.[20,22,25] Cement augmentation of the vertebrae was performed to increase the pedicle screw pullout strength, restore vertebrae stiffness to its prefractured values, and prevent new formation of adjacent-level fractures. As stiffness of the vertebral body is strongly influenced by the volume of cement injected and 14 to 16% of vertebral body volume fill was shown to restore stiffness to the predamaged values, vertebrae bodies were augmented with a minimum of 6 mL per level of cement in the lumbar vertebrae and a minimum of 4 mL per level in thoracic ones.[21,26–28] Augmentation was performed at all levels involved in the fusion and at the very least in the first mobile vertebrae below the fusion mass (transition vertebrae are prone to develop new fractures).[20–23,28–30] At the surgeon's discretion, one vertebra may be left uncemented (usually L3 or L4) to allow for future PSO.

Several studies showed direct correlation between the volume of cement injection and occurrence of pulmonary fat emboli and systemic hypotension. To reduce these risks, only 30 mL of cement was injected per procedural stage.[31,32] Because fat embolism syndrome can develop 12 to 36 hours after surgery (e.g., petechial rash, tachypnea, dyspnea, tachycardia, pyrexia, oliguria, thrombocytopenia),[32,33] we waited at least 3 days before proceeding with the next stage. Augmentation of several vertebrae per stage may be a prolonged procedure, thus we preferred to perform vertebral augmentation under general anesthesia rather than sedation. The number of stages required was based on the patients' medical condition to withstand a long operation and on the number of vertebrae needed to be augmented before the final deformity correction. Between stages, the patients were discharged home (apart from patient 1 who remained in the hospital between his third and forth stages). A detailed description of the surgical steps for each patient is presented in ►**Table 2**.

The pros and cons of a staged procedure, including the risks of repeated anesthesia, long operations, and reopening the same surgical wound, were discussed thoroughly with the patients preoperatively. All of the patients understood the complexity of the procedure and the involved risks. Nevertheless, due to the severity of their symptoms and their poor life quality, all of them agreed to undergo all stages.

Table 1 Patient characteristics and clinical scores

Patient no.	Age/sex	Fractured vertebrae involved	Bone mineral density (T score)	Body mass index	Levels fused/no. of pedicle screws used	No. of chevrons done	Pelvic Incidence	Follow-up (mo)	Back pain (0–10 numerical score)		Oswestry Disability Index (0–100%)		Thoracic kyphosis (degrees)		Lumbar lordosis (degrees)		Sagittal vertical axis (mm)	
									Pre	Post[a]	Pre	Post[a]	Pre	Post[a]	Pre	Post[a]	Pre	Post[a]
1	54/M	T6, T8, T9, L1	−2.9	25.6	T2–L3/21	8	42	38	6	2	46	16	97	37	51	29	94	42
2	56/M	T6, T8, T9,L1	−3.6	18.3	T2–L3/22	8	51	26	7	3	54	24	90	43	60	38	86	18
3	66/M	T8, T9, T10, T12, L4	−2.8	20.7	T4–L3/18	5	45	35	8	3	68	34	82	46	39	32	107	51
4	64/F	T8, T9, T10, T12	−3.2	23.8	T2–L2/18	7	43	40	8	4	71	43	90	40	56	33	25	11
5	68/F	T7, T8, T12, L1	−3.4	24.1	T2–L3/22	7	56	34	7	3	62	29	86	35	57	34	250	68

Abbreviations: Pre, preoperative; Post, postoperative.
[a]At the latest follow-up.

Surgical Technique

All patients were operated on by the senior author and underwent staged vertebral augmentation with correction of their sagittal deformity using the technique described below. All the procedures were performed under general anesthesia with the patient placed in the prone position over bolsters on a radiolucent table. Somatosensory and neurogenic motor evoked potentials were monitored throughout the last stage of the procedure (deformity correction). First-generation cephalosporin was administrated preoperatively and for 24 hours postoperatively.

First Stage (Augmentation of the Cephalad Vertebrae and Foundation Screw Insertion)

The foundation screws bear the highest pullout forces and are therefore of prime importance for construct stability.[25] Because imaging the thoracic vertebrae cephalad to T4 is technically demanding, we performed the first stage using an open technique, which relies also on anatomical landmarks for safe cement injection. Jamshidi needles (DePuy-Synthes, West Chester, Pennsylvania, United States) of 3-mm diameter were inserted into the two most cephalad vertebral bodies via the transcostovertebral route (►**Fig. 2**),[34] after which a minimum of 4 mL polymethyl methacrylate bone cement (Vertecem V, DePuy-Synthes, West Chester, Pennsylvania, United States) was injected to each vertebra. We inserted the screws through the Jamshidi tracts into the soft cement (►**Fig. 3**). Insertion of screws into half-cured cement causes cement microfractures and reduces the screw holding power.[35,36] Therefore, it is mandatory to insert the screws into the soft cement (approximately 6 minutes of cement working time) or alternatively, as a rescue procedure, to wait until the cement fully hardens (approximately 17 minutes), then drilling it with a 3.5-mm driller followed by taping and pedicle screw insertion [36]; similar screw holding power was reported when inserted into the soft or fully cured cement.[36] To increase the construct stability in our patients with osteoporosis, we chose screw insertion via the transcostovertebral route (over the transpedicular route) because it enables the use of larger-diameter screws and maximizes the screw convergence. We used large-diameter monoaxial 6.2-mm screws with cancellous bone threads, which were initially designed for anterior scoliosis correction (USS-II system, DePuy-Synthes; ►**Fig. 4**). This screw design yields a larger surface area for contact with bone or cement and was found in biomechanical studies to increase the pullout forces and construct stability.[37,38] The screws were inserted in at least 30 degrees of convergence (hence, the use of the transcostovertebral route), which was demonstrated to increase pullout forces by 28% while sustaining higher loads at the clinical threshold of loosening by 101%.[39]

Second Stage (Cephalad-to-Caudal Percutaneous Vertebral Augmentation)

The remaining thoracic and lumbar vertebrae were augmented using the transpedicular approach (►**Figs. 5** and **6**). Caudal lumbar vertebrae not involved in the fusion were also augmented in most cases to protect them from sustaining new

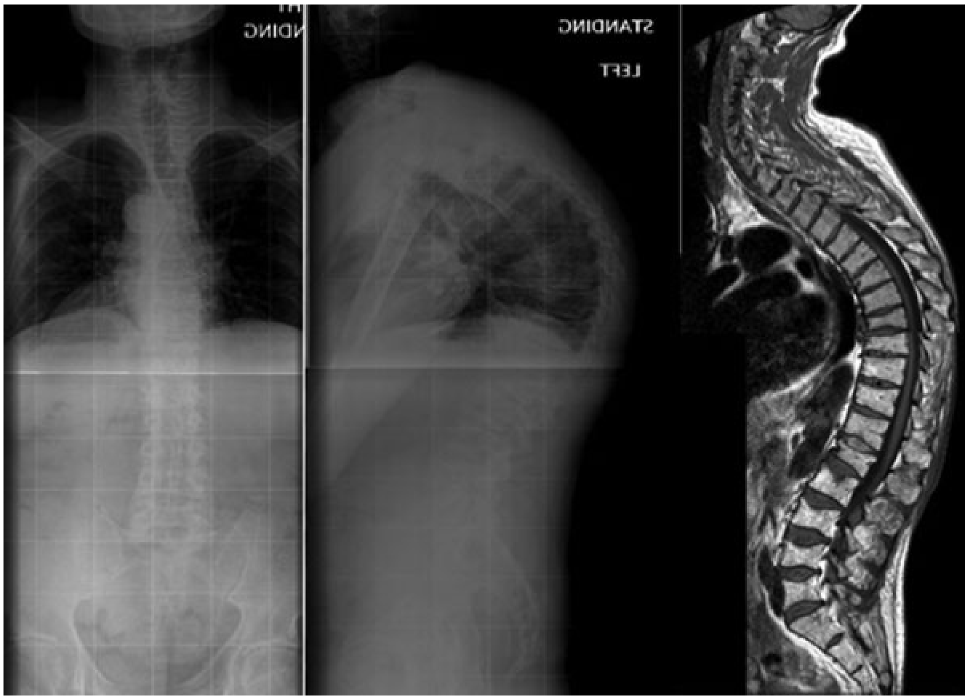

Fig. 1 A 56-year-old patient with multiple myeloma and long history of corticosteroid use with severe osteoporosis (T-score of −3.6). Preoperative standing unsupported whole-spine radiograph and sagittal magnetic resonance imaging showing thoracic kyphosis of 90 degrees, lumbar lordosis of 60 degrees, sagittal vertical axis of 86 mm, pelvic incidence of 43 degrees, pelvic tilt of 25 degrees. Multiple osteoporotic fractures at T6, T8, T9, L1.

fractures (fusion creates a long lever arm that increases compression forces on the unfused vertebrae).[13] It is our practice in severe cases of sagittal imbalance to leave the third or fourth lumbar vertebrae uncemented to accommodate for a future PSO with extension of hardware into the pelvis (►**Fig. 7**). This stage was repeated two or three times for each patient (limiting cement injection to 30 mL per procedure) until all required vertebrae were augmented.

Third Stage (Pedicular Screw Insertion and Deformity Correction)

We used an open posterior midline approach to insert monoaxial pedicle screws into all the remaining levels involved in fusion according to the principles described in stage 1. In the most caudal levels (caudal foundation screws, i.e., at least three levels caudal to the last osteotomized vertebra), 7- to 8-mm screws were used. In the remaining midthoracic vertebrae, 5.2-mm screws were used (unlike the 6.2-mm screws used in stage 1 as foundation screws). We used 5.2-mm screws as midthoracic pedicles are small (around 5-mm diameter) and more parallel with the ground, therefore axial tension (pullout) forces exerted on the screws are lesser.[40]

Thoracic deformity correction was achieved after performing multiple chevron osteotomies (►**Fig. 8A**). Extra-hard 6-mm cobalt-chrome (CoCr) rods were precontoured and attached to the cephalad foundation screws and cross-linked. Cross-linking provides both triangulation that protects against screw pullout and rotational stability.[41,42] Both rods were gently cantilevered from top to bottom across the kyphotic sections, attaching them to the screws heads one by one. We applied the cantilever corrective forces on both rods together (cross-linked) to distribute forces over a larger area and minimize the risk of screw pullout. Then, each segment was compressed across the chevron osteotomy with the use of a compressor device, shortening the posterior column and reducing the kyphosis (►**Fig. 8B**). Laminar and facet joint decortication was performed at all levels involved in fusion, followed by diluted Betadine washout (povidone-iodine 10%, Purdue Frederick Company, Stamford, Connecticut, United States). Bone graft (taken from the chevron osteotomies, decorticated laminae, and spinous processes) was packed over the decorticated laminae. Subsequently, 12 mg of bone morphogenic protein 2-soaked sponge cut into strips was placed on the bone graft to enhance fusion (Infuse, Medtronic, Minneapolis, Minnesota, United States).

Postoperatively, pneumatic compression stockings were used overnight, and anticoagulant therapy (enoxaparin 40 mg once daily) was started on the first postoperative day to reduce the occurrence of deep vein thrombosis. Patients were allowed to sit and stand under the supervision of a physiotherapist on the first postoperative day. Assisted ambulation, as tolerated, was encouraged over the first postoperative week. Return to unrestricted activity was allowed at 6-month follow-up if no signs of hardware loosening were noted on radiographs.

Outcome Measures

Clinical outcome was assessed by comparing patients' self-reported back pain (using a 0 to 10 numerical scale) and

Table 2 Detailed description of the surgical stages

Patient no.	First stage[a]	Time between stages I and II (wk)	Second stage[a]	Time between stages II and III (wk)	Third stage[a]	Time between stages III and IV (wk)	Forth stage[a]
1	Open vertebroplasty T2, T3, T5–T7 + SC screw insertion; GA; 3 h; 3 d	6	PC vertebroplasty T8–T12; GA; 2 h; 2 d	4	PC vertebroplasty L4–L5; PSA; 1 h; 2 d	0.5	Open vertebroplasty L1 and L3 with SC screw insertion, HC drilling and screw insertion into T8–T12, osteotomy and deformity correction; GA; 4 h; 6 d
2	Open vertebroplasty T2–T6 + SC screw insertion; GA; 3.2 h; 3 d	4	PC vertebroplasty T7–T12; GA; 2.5 h; 2 d	3	PC vertebroplasty L4–L5, open vertebroplasty with SC screw insertion L1–L3, HC drilling and screw insertion into T7–T12, osteotomy and deformity correction; GA; 5 h; 5 d		
3	T4–T8 open vertebroplasty + SC screw insertion; GA; 3 h; 4 d	2	PC vertebroplasty T9–L1; GA; 2.4 h; 2 d	1	PC vertebroplasty L4–L5, open vertebroplasty with SC screw insertion L2–L3, HC drilling and screw insertion into T9–L1, osteotomy and deformity correction; GA; 5 h; 6 d		
4	T2–T5 open vertebroplasty + SC screw insertion; GA; 2.5 h; 3 d	4	PC vertebroplasty T6–T12; GA; 2.5 h; 3 d	3	PC vertebroplasty L3, open vertebroplasty with SC screw insertion L1–L2, HC drilling and screw insertion into T6–T12, osteotomy and deformity correction; GA; 4.5 h; 5 d		
5	T2–T6 open vertebroplasty + SC screw insertion; GA; 2.5 h; 3 d	5	PC vertebroplasty T7–T12; GA; 2.7 h; 2 d	4	PC vertebroplasty L4–L5, open vertebroplasty with SC screw insertion L1–L3, HC drilling and screw insertion into T7–T12, osteotomy and deformity correction; GA; 5.5 h; 5 d		

Abbreviations: GA, general anesthesia; HC, hard cement; PC, percutaneous; PSA, procedural sedation with local anesthesia; SC, soft cement.
[a]Procedure performed; type of anesthesia; operative time (hours); hospital stay (days).

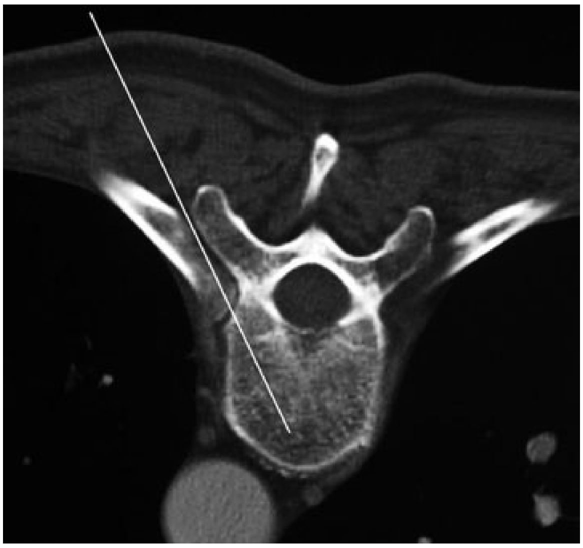

Fig. 2 Axial computed tomography demonstrating the transcostovertebral route in a thoracic vertebral body (white line). The needle is guided into the vertebral body by the cleft between the rib and the transverse process for optimal convergence.

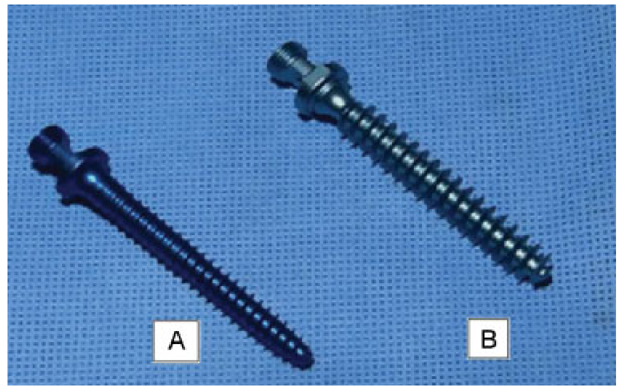

Fig. 4 (A) Cortical monoaxial pedicular screw. (B) Cancellous monoaxial screw.

related disability (using the Oswestry Disability Index [ODI], i.e., a 0 to 100% disability score, where a higher score indicates more disability and poorer function) before the operation and at the latest postoperative follow-up. Correction of the sagittal deformity was assessed by comparing preoperative unsupported standing lateral radiographs of the whole spine with postoperative radiographs at the latest follow-up. The radiographic parameters of kyphosis correction were measured digitally using a picture archiving and communication system(General Electric, Health Care Systems, Fairfield, Connecticut, United States) and included: (1) thoracic kyphosis, measured as T4–T12 Cobb angle (measurement above the level of T4 vertebrae proved unreliable as the visualization of the upper end plate on radiographs is difficult); (2) lumbar lordosis, measured as L1–S1 Cobb angle; (3) sagittal balance, defined as the displacement measured in mm of C7 plumb line in relation to the superior-posterior end plate of S1 (i.e., considered positive if anterior and negative if posterior).

Data Analysis

Outcome parameters are described as means and standard deviations. Comparisons between preoperative and postoperative values were performed using paired two-tailed *t* tests and are presented with 95% confidence intervals. Data analysis was performed with the use of MedCalc Statistical

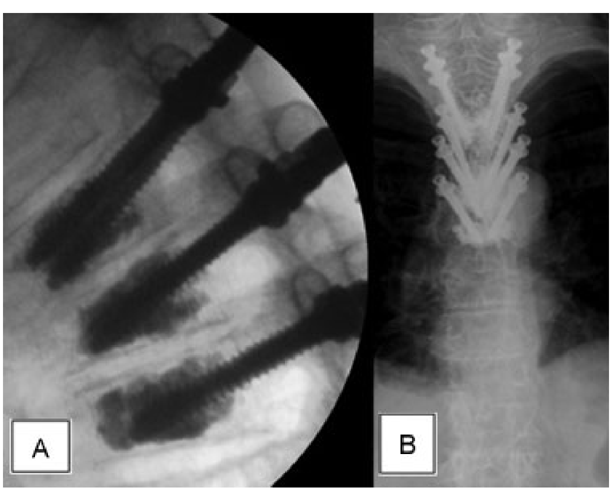

Fig. 3 First stage—cephalad cement-augmented foundation screws. (A) Lateral intraoperative radiograph using image intensifier. (B) Anteroposterior X-ray of thoracic spine.

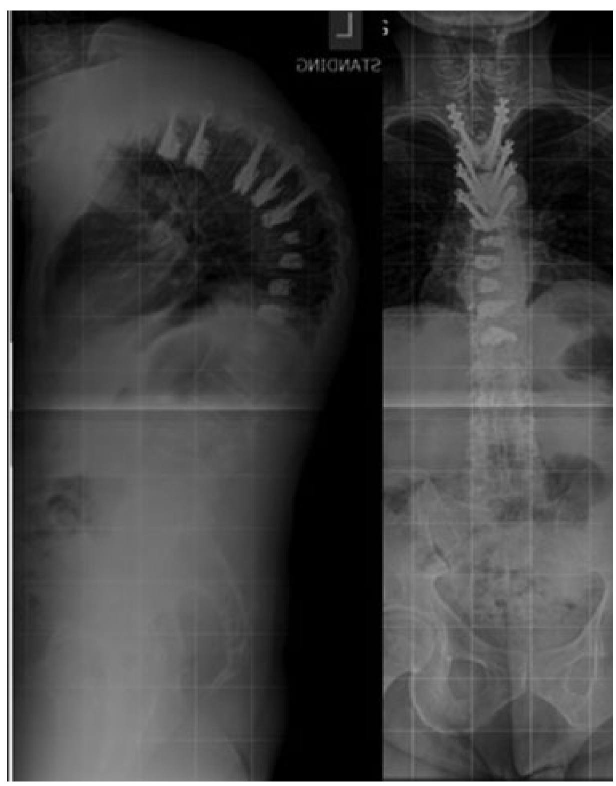

Fig. 5 Second stage—cement augmentation (vertebroplasty) of thoracic vertebrae. Lateral and anteroposterior whole-spine standing X-ray.

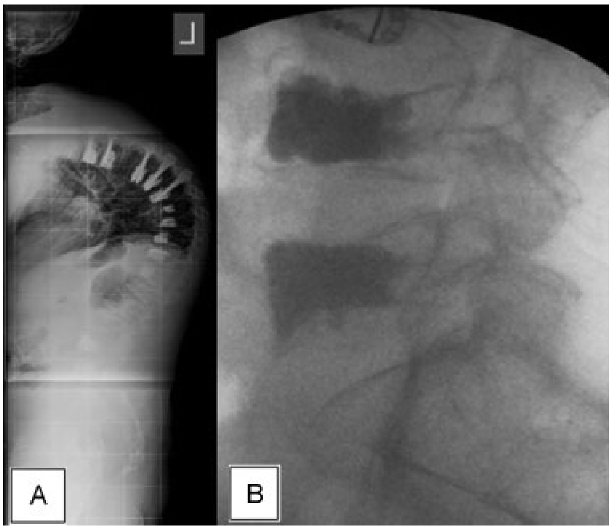

Fig. 6 Third stage—cement augmentation (vertebroplasty) of lumbar vertebrae. (A) Lateral whole-spine standing X-ray. (B) Lateral intraoperative image of lumbar spine.

Software version 15.4 (MedCalc Software bvba, Ostend, Belgium). A probability of <0.05 was considered statistically significant.

Results

Postoperatively, the mean self-reported back pain decreased by 4.2 points (from 7.2 $\pm$ 0.8 preoperatively to 3.0 $\pm$ 0.7 postoperatively on a 0 to 10 numerical scale; $p < 0.001$), and the level of disability (assessed by ODI) improved by 31% (from 60.2 $\pm$ 10% to 29.2 $\pm$ 10%; $p < 0.001$). Thoracic kyphosis, lumbar lordosis, and sagittal vertical axis decreased significantly postoperatively by 48 degrees ($p > 0.001$), 19 degrees ($p = 0.003$), and 74 mm ($p = 0.05$), respectively (►**Tables 1** and **3**).

One patient (number 4) had transient hypotension during cement injection into the T12 vertebra (second-stage procedure), which was the last vertebra injected in this stage that resolved spontaneously. Postoperatively, no clinical evidence of fat emboli was observed.

In another patient (number 2), intraoperative fluoroscopy showed cement leakage into the segmental veins during cement injection of the L2 vertebrae. The postoperative computed tomography angiography showed no evidence of cement embolus in the lungs. No neurologic complications or hardware failure occurred in any of the patients. No case of cortical screw breach was found on follow-up radiographs.

Discussion

Multilevel osteoporotic vertebral compression fractures may lead to considerable thoracic deformity and sagittal imbalance, which may necessitate surgical intervention.[1,6,13] Traditional lumbar PSO with S1 and pelvic fusion techniques for sagittal balance correction have been associated with a high rate of hardware failure, loss of lumbar mobility, and residual thoracic hump.[17] This study presents our experience with surgical correction of severe debilitating thoracic kyphosis

Fig. 7 A 64-year-old patient with ulcerative colitis and long history of corticosteroid use with severe osteoporosis (T-score of −3.2). Pre- and postoperative standing unsupported whole-spine radiograph showing thoracic kyphosis of 90 degrees corrected to 40 degrees. Instrumented fusion of T2–L2 and cement augmentation of L3 protecting against future fracturing while leaving L4 for future subtraction osteotomy and pelvic fusion if needed.

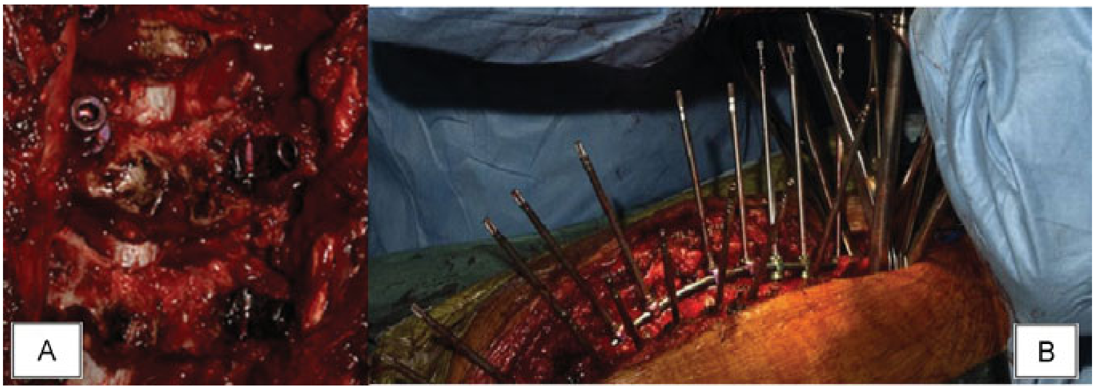

Fig. 8 (A) Chevron osteotomy thoracic vertebrae. (B) Deformity correction, insertion of rods.

unresponsive to nonoperative treatment in patients with multilevel osteoporotic vertebral compression fractures.

Several studies reported outcomes of the treatment of single-level osteoporotic fracture with focal kyphosis and neurologic deficit. Fuentes et al reported on 16 patients treated with decompression, open kyphoplasty, and short-segment instrumented posterolateral fusion without cement augmentation of adjacent vertebrae.[12] At a mean postoperative follow-up of 18 months, all the patients improved clinically and no hardware failure or adjacent-level fracture was observed. Patil et al reported on 24 patients, of whom 14 had less than 30 degrees of kyphosis and 10 had 30 to 50 degrees.[13] Those patients were treated with decompression, deformity correction, and instrumented posterolateral fusion. At 25-month follow-up, patients' pain rating, functional scores (ODI), and sagittal deformity were significantly improved. Two cases (8.3%) of pedicle screw pullout occurred. Although the pathologies were similar to those of our patients and the results are encouraging, the correction described was for a single-level osteoporotic fracture operated due to neurologic deficiencies and not due to sagittal imbalance.

In contrast, our series consists of fractures of at least four vertebrae with greater extent of sagittal deformity and loss of sagittal balance in neurologically intact patients. Nevertheless, at a mean postoperative follow-up of 34 months, our patients' clinical outcome (e.g., pain relief, disability rating) and deformity correction parameters were comparable to those reported in these previous studies.[12,13]

Several fixation options (e.g., pedicle screws, hooks, sublaminar wires) are available for correction of spinal deformities. Laminar hooks are most resistant to failure from posteriorly directed forces in unaugmented osteoporotic vertebrae.[18] Nevertheless, in vertebrae with normal bone density (augmented vertebrae), pedicular screws showed the best pullout forces prior to failure and the ability to support a greater magnitude of deformity correction in comparison with hooks and sublaminar wires.[43–45] For these reasons, we preferred using pedicular screws in our patients. Loosening and pullout of pedicle screws remain major concerns in patients with severe osteoporosis. Wu et al showed that pullout strength was lower when pedicle screws were inserted into severe osteoporotic vertebrae and that screw fixation strength can be increased by cement augmentation of the vertebral body.[14] Other studies showed 119 to 250% increase in screw pullout strength after cement injection, as well as increased mean stiffness, energy absorbed to failure, and initial fixation strength. Fenestrated pedicle screws and expandable screws were shown to improve the pullout strength.[41–43] However, the advantage of using these screws over standard screws with vertebral cement augmentation remains questionable.[46,47] To reduce the risk of screw pullout in our cohort, we augmented the vertebrae bodies with cement prior to standard screw insertion and indeed no screw pullout occurred at a mean of 34-month follow-up despite the magnitude of deformity that was corrected.

Table 3 Summary of outcome measures

	Preoperative	Postoperative	Difference (95% CI)[a]	*p* Value
VAS (0–10 scale)	7.2 ± 0.8	3.0 ± 0.7	4.2 (3.6–4.7)	<0.001
ODI (0–100%)	60.2 ± 10	29.2 ± 10	31.0 (28–34)	<0.001
Thoracic kyphosis (degrees)	89.0 ± 5	40.2 ± 4	48.8 (38–59)	<0.001
Lumbar lordosis (degrees)	52.6 ± 8	33.2 ± 3	19.4 (10–28)	0.003
Sagittal vertical axis (mm)	112.4 ± 83	38.0 ± 23	74.4 (−4–153)	0.058

Abbreviations: ODI, Oswestry Disability Index; VAS, visual analog scale.
Note: Values are presented as mean ± standard deviation. Comparisons were made using paired two-tailed *t* test.
[a]The difference between the groups is presented as an absolute value.

The optimal pedicle screw density (i.e., the number of pedicle screws used divided by the number of available pedicle insertion sites) required to maintain a stable fixation following correction of spinal deformities remains controversial. [48,49] Foundation screws (i.e., screws placed into the two upper and two lower vertebrae involved in fusion) are of prime importance as they sustain most of the corrective forces,[25] thus we prefer to insert screws into both pedicles (100% screw density) in these levels, potentially lowering the failure rate. In the remaining levels, we found in a previous study that introducing one screw per level in an alternating fashion (around 65% screw density, as shown in ►**Figs. 7** and **9**) provides similar deformity correction power while reducing operating time, hardware costs, and the potential complication of screw malpositioning.[48]

Regarding the fixation rods, we preferred to use the stiffer CoCr rods over titanium or stainless steel alloys. Although the extremely stiff CoCr rods are often not recommended for use in patients with osteoporosis, we believe that our practice of augmenting all vertebrae prior to deformity correction reduces the risk of hardware failure even with the use of such stiff rods. Furthermore, stiffer CoCr rods have greater yield strength than titanium or stainless steel alloys,[50] which potentially allows better correction and maintenance of correction in larger deformities.[51–53] Recent studies showed that contouring rods prior to their use creates stress-rising defects in the alloy, which reduce fatigue life due to failure.[50,51] CoCr rods are less affected by notching and are less likely to break and therefore may prolong the construct longevity, enabling more time for fusion to ensue.[50,51]

Adjacent-level fracture following spinal fusion is another concern, particularly in the osteoporotic spine.[13] Several studies have suggested that prophylactic vertebroplasty may reduce the risk of adjacent-level failure following extended spinal fusions.[54,55] For these reasons, we favor augmenting all the adjacent-level vertebrae not involved in the fusion.

The mean pelvic incidence and preoperative lumbar lordosis of our patients were 47.4 degrees and 52.6 degrees, respectively, quite similar to the values reported by Roussouly et al for normal populations.[56] Postoperatively, a decrease in the lumbar lordosis was observed in all our patients (to a mean of 33.2 degrees, well below the expected value for their pelvic incidence). We assume this postoperative decrease in lumbar lordosis reflects the lever arm effect of the long fused segment on the remaining mobile lumbar segment. Unfortunately, this postoperative decrease in lumbar lordosis shifted the sagittal balance anteriorly (a mean positive sagittal balance of 38 mm remained postoperatively), compromising our effort of achieving as neutral sagittal balance as possible. Further correction (PSO) of L3 or L4 levels (which can be left uncemented for this purpose) may enable additional sagittal correction. Nevertheless, considering the substantial clinical improvement of our patients, further intervention seems not indicated.

Cement leak was reported in 11 to 73% on cases of vertebroplasty in previous studies,[57,58] and our results are in the lower edge of this range (we had one case of cement leakage into the segmental veins) despite the multiple levels injected and the relatively large volume of cement used (approximately 70 mL of cement per patient). Our encouraging results may reflect the fact that we injected the cement into nonfractured, healed vertebrae whereas most cement leaks occur during cement injection into fresh osteoporotic

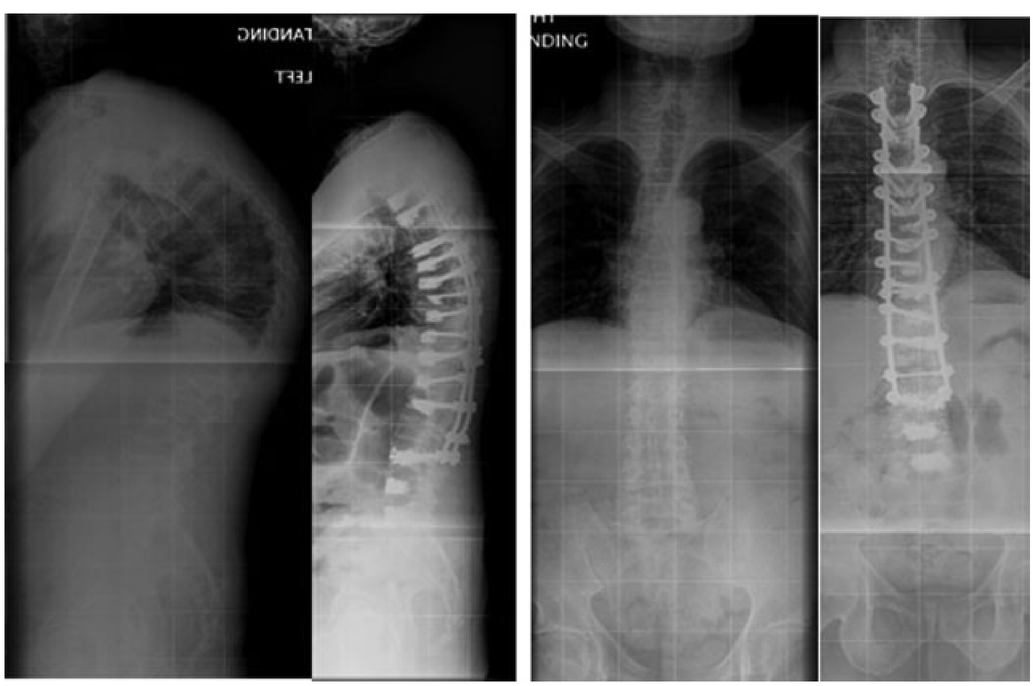

Fig. 9 Preoperative and postoperative whole-spine radiograph. Instrumented fusion T2–L3, L4, and L5 vertebrae cement-augmented without fusion. Correction of thoracic kyphosis from 90 to 43 degrees.

vertebrae fractures. Furthermore, to minimize the risk of cement leak, we used medium viscosity cement. However, we used only intraoperative fluoroscopy and plain radiographs to detect cement leakage, which were shown to detect only 34% of leaks,[57] and therefore the true rate of cement leaks in our patients may be higher.

Our study has several limitations. First, this retrospective study had a very limited cohort and relatively short follow-up. However, considering that surgical correction of severe thoracic kyphosis resulting from multilevel osteoporotic vertebral fractures is uncommon, these limitations seem unavoidable. Second, it was a single-arm study with no control group. Therefore, it is difficult to conclude whether our approach would be superior to other alternatives. Finally, our cohort's characteristics (relatively young patients with osteoporosis secondary to prolonged steroid medication) differed from the common characteristics of patients with osteoporotic vertebral fractures (elderly patients with primary osteoporosis). Whether elderly patients with severe kyphotic deformity would respond similarly to the major operation described here remains unclear.

Conclusion

The surgical technique described in this study offers a safe and effective method of treating severe thoracic kyphosis with symptomatic sagittal imbalance in patients with multilevel osteoporotic vertebral compression fractures. Further studies with larger cohorts and longer follow-up are required to assess the long-term outcomes of such major operations in these challenging cases.

Disclosures
Eyal Behrbalk: none
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