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Review article

Surgical management of osteoporotic vertebral fractures: current approaches. Literature review

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Abstract

Osteoporotic vertebral fractures represent one of the most prevalent and clinically significant complications of systemic osteoporosis, particularly in elderly patients. Reduced bone mineral density compromises the mechanical stability of spinal instrumentation and increases the risk of postoperative construct failure. This literature review analyzes studies retrieved from PubMed, Scopus, and Web of Science databases covering the period from January 2015 to April 2025. Included sources comprise original articles, randomized controlled trials, meta-analyses, and systematic reviews focused on the surgical treatment of osteoporotic vertebral fractures.

The review summarizes contemporary surgical strategies aimed at improving fixation strength and optimizing clinical outcomes in patients with spinal osteoporotic lesions. Special attention is given to cement-augmented pedicle screws, expandable and fenestrated implants, cortical bone trajectory systems, as well as minimally invasive procedures such as vertebroplasty and kyphoplasty.

Available evidence demonstrates that the use of bone cement significantly increases pedicle screw pullout strength and reduces the incidence of postoperative complications.

Kyphoplasty additionally enables partial deformity correction and provides effective pain relief.
The findings highlight the importance of an individualized approach to surgical planning, taking into account bone quality and anatomical characteristics of the affected segment. Such tailored strategies are critical to reducing the risk of revision surgeries and achieving stable, long-term functional outcomes.

Keywords: osteoporosis, pathological fracture, transpedicular fixation, cement augmentation, expandable screws, bicortical fixation, kyphosis, vertebroplasty, kyphoplasty.

1. Introduction

Osteoporosis is a major global health concern, contributing significantly to the rising incidence of vertebral body fractures resulting from decreased bone mineral density and structural deterioration.

According to the Global Burden of Disease study (2019) by the World Health Organization (WHO), an estimated 8.6 million new cases and 5.3 million prevalent cases of vertebral compression fractures were reported worldwide. This marks a 38% increase since 1990, reflecting both the aging of the global population and demographic expansion. Regional prevalence rates vary, ranging from 18–26% among women in Europe to 9-24% in Asian countries [1].

The WHO as a priority non-communicable, age-related disease, alongside cardiovascular and oncological disorders, recognizes osteoporosis. It is estimated that one in three women and one in five men over the age of 50 will experience an osteoporotic fracture during their lifetime, with vertebral fractures being the most common site (World Health Organization, 2021) [2].

This condition has a direct impact on diagnostic and therapeutic decision-making in patients with vertebral injuries. As life expectancy increases and global populations continue to age, the incidence of osteoporotic fractures is projected to rise further. This trend is expected to result in higher rates of disability and mortality, as well as an increasing burden on healthcare systems worldwide [3-5].

Reduced bone mineral density is a key risk factor for mechanical instability of the spinal segment during surgical intervention. In addition to this, age-related remodeling of bone tissue, degradation of the bone matrix, and the presence of comorbid somatic conditions further compromise the effectiveness of conventional spinal fusion techniques. In this context, the development and implementation of advanced fixation methods, the use of innovative biomaterials, and the application of both antiresorptive and anabolic therapies aimed at enhancing bone metabolism have gained increasing importance. Emerging strategies incorporating elements of bioengineering and personalized treatment planning allow for the adaptation of surgical approaches to the patient's individual anatomical and functional characteristics, thereby expanding the possibilities for stabilizing the osteoporotic spine [6].

Global demographic shifts have led to a substantial increase in spinal surgeries among elderly patients. For example, in the United States alone, the rate of spinal procedures among individuals covered by the Medicare program increased more than fifteen-fold between 2001 and 2007. A significant proportion of these patients are over the age of 50, with osteoporosis frequently remaining underdiagnosed. It is estimated that up to 50% of women in this age group who undergo spinal surgery exhibit signs of osteoporosis a prevalence notably higher than in age-matched populations without surgical intervention [7]. This highlights the critical need for routine osteoporosis screening in this patient cohort, as well as the timely initiation of therapies aimed at reducing fracture risk and improving surgical outcomes [8].

According to estimates from the WHO and leading clinical societies as of 2021-2022, up to 70% of osteoporotic vertebral body fractures remain undiagnosed in a timely manner, often due to their asymptomatic nature or presentation with nonspecific complaints. This underdiagnosis significantly increases the risk of subsequent fractures and worsens long-term outcomes [9].

Stabilizing surgical interventions are typically indicated in the presence of specific factors, including spondylolisthesis, severe pain associated with degenerative scoliosis, the need for extensive or multilevel decompression involving facet joint resection, and in cases of recurrent spinal canal stenosis [10].

Vertebral compression fractures, particularly at the thoracolumbar junction, are highly prevalent among

older adults. In patients with osteoporosis, bone architecture is significantly disrupted: osteoblast activity is reduced, the balance between bone formation and resorption is impaired, and the osteoconductive and osteointegrative properties of bone are diminished. These changes lead to reduced construct stability during transpedicular fixation, an increased risk of spinal fusion failure, subsequent compressive events, and progressive spinal deformity [11].

2. Methodology

We conducted this review in accordance with the PRISMA 2020 guidelines (Preferred Reporting Items for Systematic Reviews and Meta-Analyses). We searched the international bibliographic databases PubMed, Scopus, and Web of Science for relevant literature published between January 2015 and April 2025. To identify eligible studies, we used the following keywords and their combinations: "osteoporotic vertebral fracture", "pathological spinal fracture", "cement augmentation", "expandable pedicle screws", "bicortical fixation", "vertebroplasty", "kyphoplasty" and "instrumentation in osteoporosis".

We included original studies, randomized controlled trials (RCTs), meta-analyses, and systematic reviews that focused on the surgical treatment of pathological vertebral fractures associated with systemic osteoporosis. Specifically, we considered studies that examined spinal stabilization techniques involving transpedicular fixation, cement augmentation, expandable or bicortical screws, and minimally invasive procedures such as vertebroplasty and kyphoplasty. We also reviewed biomechanical studies that assessed construct stability and clinical outcomes following surgery.

We excluded narrative reviews without original data, case reports, letters to the editor, studies involving traumatic or neoplastic fractures, and articles that lacked a clear description of surgical techniques.

From the included studies, we extracted data on the type of intervention, characteristics of spinal fixation, use of cement augmentation, clinical outcomes (including refracture rates and complications), and radiological parameters such as local kyphosis, vertebral body height, and construct stability.

3. Results

Spinal instrumentation techniques are increasingly used in the treatment of complex spinal deformities, including scoliosis and degenerative kyphosis. Epidemiological studies have shown that scoliotic changes are present in 36–48% of women with osteoporosis, and severe deformity is frequently associated with significantly reduced bone mineral density [12]. Research has demonstrated that the pullout strength of pedicle screws in osteoporotic patients is markedly reduced, primarily due to microinstability within the vertebral body and poor engagement of the screw with trabecular bone. These factors contribute to construct failure in up to 12% of cases, particularly in multilevel fixation procedures [13, 14].

Early postoperative complications (within three months) include failure of fixation components, epidural hematoma formation, and compression fractures of adjacent vertebrae due to increased stress on load-bearing segments [14, 15].

Late complications, typically occurring after the three-month postoperative period, include non-union (pseudarthrosis), secondary fractures, loosening of fixation screws, adjacent segment compression, and severe pelvic pain, particularly when iliac screws are used. Additional issues may include discogenic herniation, facet joint collapse, and proximal junctional kyphosis (PJK), which often develops at the interface between rigidly fixated and mobile spinal segments (Figures 1, 2).

Proximal junctional kyphosis is especially common among elderly patients with sagittal imbalance and osteoporosis, and it increases the risk of postoperative spinal instability and the need for revision surgery. Contributing factors include mismatch between the level of construct termination and physiological transition zones, as well as insufficient fixation length.

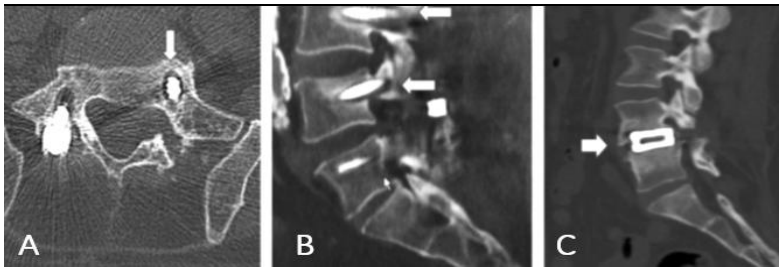

Figure 1 – (A) Axial CT scan and (B) sagittal reconstruction showing bone destruction around pedicle screws (indicated by arrows), characteristic of pseudarthrosis; (C) sagittal CT image demonstrating implant subsidence. (Image from the author's personal archive)

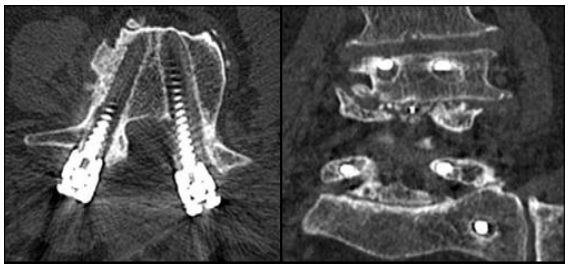

Figure 2 – Bone resorption around pedicle screws observed 12 months after surgery. (Image from the author's personal archive)

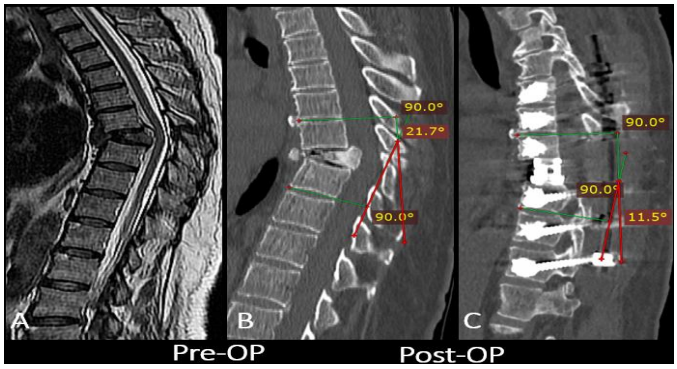

Figure 3 – A 59-year-old female patient presented with lower back pain that began three months earlier following heavy lifting, later accompanied by neurological symptoms in the form of lower limb paresis. (A) T2-weighted MRI shows signal loss in the Th8 vertebral body. (B) CT scan reveals kyphotic deformity and collapse of the Th8 superior endplate. (C) Postoperative CT demonstrates posterior decompression, anterior spinal fusion using a V-LIFT cage, transpedicular fixation with vertebroplasty, restoration of sagittal alignment, and decompression of the spinal canal. (Image from the author's personal archive)

Osteoporosis is a major risk factor in spinal surgery, particularly in multilevel-instrumented spinal fusion procedures [13]. In patients over the age of 65 who undergo instrumentation involving five or more spinal levels, the most frequently reported complications include compression fractures of the uppermost adjacent segment and the development of kyphotic deformity, which occurs in approximately 28% of cases [16]. Several studies have further confirmed that proximal junctional kyphosis (PJK) is the most common complication following long-segment spinal stabilization [17].

The Scoliosis Research Society defines PJK as a Cobb angle of ≥20° between the upper-instrumented vertebra and the two vertebrae above it (see Figure 3). Clinicians have identified this deformity in up to 39% of patients, most commonly between the sixth and eighth postoperative weeks. Key risk factors include advanced age, compromised bone quality, and marked preoperative sagittal imbalance. Approximately one-third of patients who develop PJK require revision surgery within the first five months due to construct failure and spinal instability.

A preoperative thoracic kyphosis exceeding 30° has been identified as an independent predictor of PJK, while effective correction of sagittal imbalance can reduce its incidence from 45% to 19% [18].

Surgical Strategies for Pathological Vertebral Fractures in Osteoporotic Patients

Osteoporosis significantly compromises the reliability of spinal fusion and the stability of implant fixation, particularly in elderly patients with low bone mineral density. In response, surgical strategies have been specifically developed to improve stabilization outcomes in this vulnerable population. When determining the optimal surgical approach, it is essential to account for common failure mechanisms associated with osteoporotic bone, such as poor screw purchase, micro-instability at the bone–implant interface, and early loss of fixation. Modern surgical techniques focus on addressing these challenges through a combination of mechanical augmentation, extended fixation constructs, and biologically supportive interventions.

Extended Instrumentation Techniques

One of the most effective approaches to improving construct stability in osteoporotic patients is the extension of the transpedicular fixation zone. It is generally recommended to span at least three vertebral segments above and below the pathologically altered level. This extended fixation enables more uniform distribution of biomechanical loads and reduces stress on individual screws, which is especially important in the context of low bone mineral density. This technique is particularly relevant for elderly patients with spinal deformities, who are at increased risk of implant loosening and loss of correction [6, 19, 20].

An additional reinforcement option involves the use of hybrid systems that combine pedicle screws with sublaminar wires or hooks. These combined constructs enhance the overall mechanical stability of the system, reduce the likelihood of micromotion at the fixation points, and promote improved fusion formation. Despite their biomechanical advantages, hybrid systems remain limited in widespread clinical use due to technical complexity and increased operative time [10].

The incorporation of cross-links into the construct is also considered a method for improving stability. Cross-links reduce rotational and axial forces acting on the instrumentation system and may help prevent screw migration or mechanical failure. Experimental studies have demonstrated that even a single cross-link can increase the construct's resistance to torsional forces and screw pullout, especially in multilevel stabilization procedures [21]. However, in osteoporotic bone, the efficacy of cross-links may be diminished due to the reduced holding capacity of the weakened bone tissue, necessitating a more cautious and individualized approach to their use in this patient population.

Technical Modifications in Pedicle Screw Placement

The stability of pedicle screw fixation depends on a range of factors, including the anatomical and geometric characteristics of the vertebrae, bone quality, and the structural design of the implants. As highlighted in several studies [13, 22, 23], these parameters form the foundation for achieving solid screw anchorage and overall construct reliability. Among these, bone mineral density plays a particularly critical role, especially in osteoporotic patients.

Reduced bone density has a direct impact on the mechanical strength of fixation. Zhou et al. [24] demonstrated that a decrease of just 100 mg/cm² in bone mineral density leads to a reduction in holding strength by approximately 10 kPa. Other authors have similarly confirmed a strong correlation between bone mineralization levels and pedicle screw pullout strength [25].

One of the most crucial technical steps in screw placement is the creation of the pilot hole. In osteoporotic bone, the selection of the pilot hole diameter is especially important. An excessively wide hole compromises thread engagement with the surrounding bone, while a hole that is too narrow increases insertional torque and raises the risk of cortical damage, including potential pedicle fracture. Therefore, pilot hole diameter and depth should be optimized based on the patient's individual morphometric features and bone quality [22].

In standard cases, tapping the screw trajectory before insertion helps maintain control and reduces the risk of trajectory deviation. However, in osteoporotic bone, this step may actually weaken fixation by disrupting the already fragile trabecular structure. Studies have shown that in the lumbar spine, inserting screws without prior tapping or using smaller-diameter

taps results in higher pullout strength, indicating better screw–bone interface stability. In contrast, this trend is not observed in the thoracic spine, possibly due to anatomical differences in vertebral morphology and cortical distribution [25].

Thus, the technique of pedicle screw placement should be adapted according to the surgical level, bone mineral density, and the specific clinical context. Optimizing pilot hole preparation and selecting an appropriate tapping method are critical steps in improving fixation reliability in osteoporotic bone.

Bicortical fixation is based on utilizing the mechanical strength of the cortical bone layer, which offers significantly greater resistance compared to cancellous bone. This technique ensures more secure anchorage of the implant compared to traditional unicortical fixation, which primarily relies on trabecular bone. The method involves the insertion of small-diameter, fine-threaded screws that pass through the dense cortical shell of the vertebral arch and articular processes, rather than only through the cancellous core of the vertebral body as in conventional transpedicular fixation [26, 27]. A key feature of this technique is the reversed screw trajectory – extending from the medial surface near the spinal canal toward the lateral side – which allows engagement of denser cortical regions. This trajectory enhances implant bone interface strength, improving construct stability and resistance to micromotion and pullout.

However, extending screw trajectories near neurovascular structures carries specific risks. These include potential injury to the sacral sympathetic trunk, major vessels (such as the aorta and inferior vena cava), and intra-abdominal organs—particularly during instrumentation near the lumbosacral junction [28]. Therefore, bicortical screw fixation is typically performed in anatomically safe zones, such as cranial or ventral to the superior endplate of the S1 vertebra, where the risk of intraoperative complications is considerably lower.

Biomechanical studies have shown that bicortical screw placement substantially enhances rotational stability and pullout resistance under cyclic loading conditions, outperforming traditional anteromedial screw trajectories in terms of construct durability and mechanical reliability [23–24].

In the sacral region, surgeons often utilize a tricortical screw trajectory, directing the implant toward the apex of the S1 promontory. This approach enables simultaneous engagement of three cortical surfaces—the posterior, lateral, and anteriosuperior walls of the vertebral body. Despite their smaller diameter and shorter length compared to conventional pedicle screws, cortical screws achieve higher insertional torque and demonstrate greater pullout resistance in osteoporotic bone [23].

To date, only one randomized clinical trial has evaluated the outcomes of traditional transpedicular screw placement versus cortical screw trajectory. According to the results, the rate of solid bone fusion assessed by CT at 12 months postoperatively was 89.5% (n = 39) in the conventional technique group and 92.1% (n = 38) in the cortical screw group. Moreover, no significant differences were found between the groups in terms of leg pain reduction or Oswestry Disability Index scores. However, the cortical screw group demonstrated significantly reduced intraoperative blood loss, shorter operative times, and decreased incision length advantages attributed to the fact that cortical screw placement does not require exposure of the facet joints [27].

Modification of Pedicle Screw Design

One of the key strategies for improving fixation reliability in osteoporotic spines involves the optimization of pedicle screw geometry. Increasing the screw's diameter and length enhances pedicle fill and improves contact with the cortical bone. By enlarging the surface area between the screw threads and the surrounding bone, the implant achieves greater holding strength an especially important consideration in anatomically vulnerable regions such as the sacrum. Studies have confirmed that longer and wider screws exhibit superior mechanical stability and significantly reduce the risk of construct failure, particularly in osteoporotic conditions [19, 22, 25].

Screws with conical geometry are of particular interest. These implants feature either tapered threading, a tapered core, or both. Screws with a constant outer diameter and a tapered internal shaft generate a stiffness gradient along their length, which enhances thread engagement with the trabecular bone inside the vertebral body. This design is especially beneficial for patients with low bone mineral density, where traditional cylindrical implants may fail to provide adequate fixation. Experimental data indicate that conical screws achieve higher pullout strength compared to conventional screw designs under similar loading conditions [29].

In patients with severe osteoporosis, conventional transpedicular fixation may prove insufficient for achieving reliable stabilization. In such cases, alternative approaches are considered, including the Midline Lumbar Fusion (MidLF) technique, which involves the placement of screws along a medial trajectory that primarily engages dense cortical bone structures. This technique reduces surgical invasiveness while maintaining adequate mechanical strength, particularly for short-segment constructs.

Another widely used method to enhance fixation in osteoporotic bone is cement augmentation. This can be performed via two main techniques: (1) injection of polymethylmethacrylate (PMMA) cement through cannulated, fenestrated screws; or (2) pre-filling the prepared pilot hole with cement using a bone access needle prior to screw insertion. In both methods, a robust cement "mantle" forms around the screw, significantly improving resistance to pullout and mechanical loosening. This technique is especially beneficial in vertebral bodies with severely compromised bone quality, where intrinsic bone retention is inadequate for safe screw implantation [30] (Figure 4).

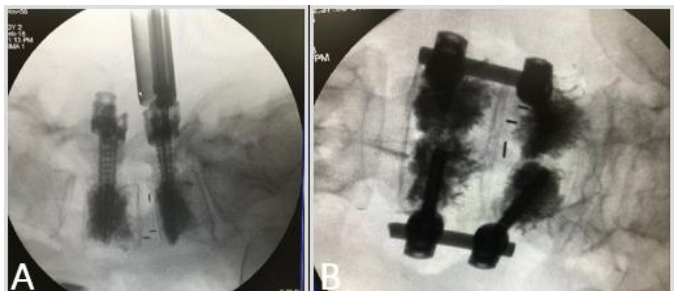

Figure 4 – (A) and (B) Cement augmentation in osteoporotic vertebral bodies using cannulated, fenestrated pedicle screws. Intraoperative fluoroscopic images in lateral and anteroposterior projections. (Image from the author's personal archive)

Transpedicular Fixation with Cement Augmentation

In recent years, the use of cement augmentation to improve the stability of pedicle screw fixation in osteoporotic spines has gained increasing attention. This technique involves injecting bone cement—most commonly polymethylmethacrylate (PMMA)—into the trabecular bone to form a rigid mantle that redistributes mechanical loads and compensates for the diminished holding strength of osteoporotic bone. By creating a stable interface with the vertebral architecture, PMMA significantly increases screw pullout resistance, with reported improvements ranging from two- to five-fold compared to non-augmented constructs. These effects have been consistently confirmed by in vitro biomechanical studies and clinical outcomes in high-risk patient cohorts [31]. Cement augmentation is particularly indicated in patients with severely reduced bone mineral density and intervertebral instability, where standard fixation techniques often fail to achieve adequate mechanical reliability.

Cement delivery techniques include: (1) the use of cannulated, fenestrated screws that allow direct injection of cement into the vertebral body; and (2) pre-filling the screw channel with cement before inserting the implant into the stabilized bone [32]. Both approaches aim to improve the biomechanical strength of the fixation and reduce the risk of construct failure. However, the procedure requires strict adherence to technical protocols and careful control of cement dispersion, as there is a risk of extravasation into venous plexuses, the spinal canal, or surrounding soft tissues

Risks of Cement Augmentation and the Use of Expandable Screws

Despite its proven clinical efficacy, cement augmentation carries several potential complications related to the use of bone cement. The most frequently reported adverse events include cement extravasation into venous structures, which may lead to thromboembolic events, and leakage into the spinal canal, posing a risk of neural compression. However, existing data suggest that most of these complications are asymptomatic and are typically identified only through postoperative imaging. Nevertheless, these risks underscore the importance of strict adherence to procedural protocols and continuous fluoroscopic monitoring throughout all stages of cement injection [33].

Expandable Pedicle Screws

As part of the ongoing search for optimal surgical solutions in the treatment of osteoporotic vertebral fractures, screw designs with mechanically expandable components have been developed and introduced into clinical practice [34]. These screws are equipped with a specialized mechanism that allows expansion of the distal portion of the implant—located within the vertebral body—after insertion. Notably, the pedicle itself remains intact, preserving the external anatomical contour and reducing the risk of intraoperative injury (Figure 5).

The expansion mechanism compresses the surrounding trabecular bone, resulting in local densification and improved mechanical interlock with the implant. Experimental studies have demonstrated that expandable screw designs can increase pullout strength by up to 50% compared to conventional screws in osteoporotic bone [35]. Additional stability gains can be achieved when expandable screws are combined with cement augmentation, where cement is introduced after expansion to form a dense mantle around the implant.

Despite their clear biomechanical advantages, expandable screws also present certain limitations. A major drawback is the technical complexity of revision procedures, particularly when implant removal is necessary. The tight engagement between the expanded component and the surrounding bone often makes extraction challenging and potentially traumatic, rendering revision surgeries more invasive and associated with greater risk [34].

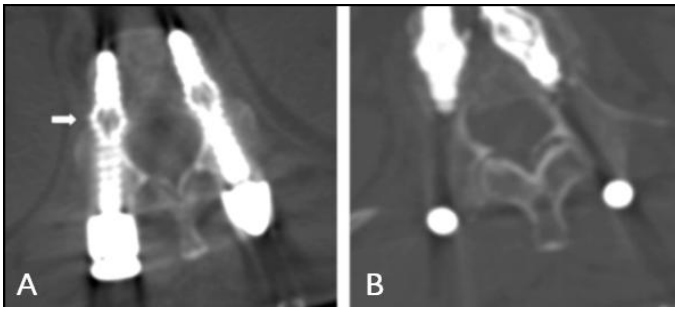

Figure 5 –CT images showing expandable pedicle screws (A) and (B). The arrow indicates the expansion zone within the vertebral body [34]

Prevention of Kyphotic Spinal Deformities

One of the most challenging aspects of surgical management in patients with osteoporotic changes is the prevention of postoperative kyphosis, particularly when combined with scoliotic deformity [36]. According to the kyphoscoliosis classification, two primary types are distinguished: Type I is characterized predominantly by lumbar scoliosis without a significant rotational component, while Type II involves pronounced kyphotic curvature accompanied by vertebral rotation and substantial torsional imbalance [37]. For Type I deformities, short-segment instrumentation is often sufficient to achieve local stabilization. In contrast, Type II kyphoscoliosis typically requires long-segment fixation that addresses both angular deformity and rotational imbalance.

The optimal surgical strategy for these complex deformities remains a topic of ongoing debate. However, most authors emphasize the importance of thorough neural decompression to achieve durable clinical outcomes. The prevailing surgical approach for severe deformities includes multilevel laminectomy followed by transpedicular fixation (TPF) that spans either the entire deformity or the most unstable segments [38].

To date, there is no universally accepted strategy for preventing postoperative kyphotic progression. However, both clinical experience and evidence from the literature highlight several principles that may reduce the risk of secondary kyphosis. These include contouring the support rod to restore physiological sagittal alignment based on the patient's preoperative kyphosis; using transverse process hooks on the uppermost vertebrae to enhance terminal construct stability; and avoiding fixation across segments with pre-existing kyphotic deformity unless required for neural decompression. Preoperative assessment of bone mineral density is particularly important, as osteoporotic bone is a strong predictor of both construct

failure and postoperative deformity progression. Osteoporosis management prior to surgery is considered an essential component of the multidisciplinary approach. Among additional preventive strategies, prophylactic vertebroplasty of one or two levels above the instrumentation has been proposed to reduce the risk of fractures and structural failure in vulnerable adjacent segments.

Clinical Approach and Case Observation

At our center, we apply a comprehensive management protocol for patients with degenerative kyphoscoliosis complicated by osteoporotic changes. The surgical strategy involves thorough decompression of neural elements within the spinal canal and long-segment stabilization, either using transpedicular systems or Midline Lumbar Fusion (MidLF) constructs, depending on the anatomical and functional characteristics of each case.

All procedures were performed under operative microscopic visualization and included laminectomy using microsurgical instruments to minimize neurological risks. As an illustrative example, we present a clinical case from our practice involving a late complication following percutaneous vertebroplasty. The patient presented with progressive lumbar spinal deformity and segmental instability that developed after a previously performed minimally invasive procedure. A combined surgical strategy was employed, consisting of transpedicular fixation, kyphotic deformity correction, and cement augmentation of structurally compromised segments. Further details are provided in Figure 6.

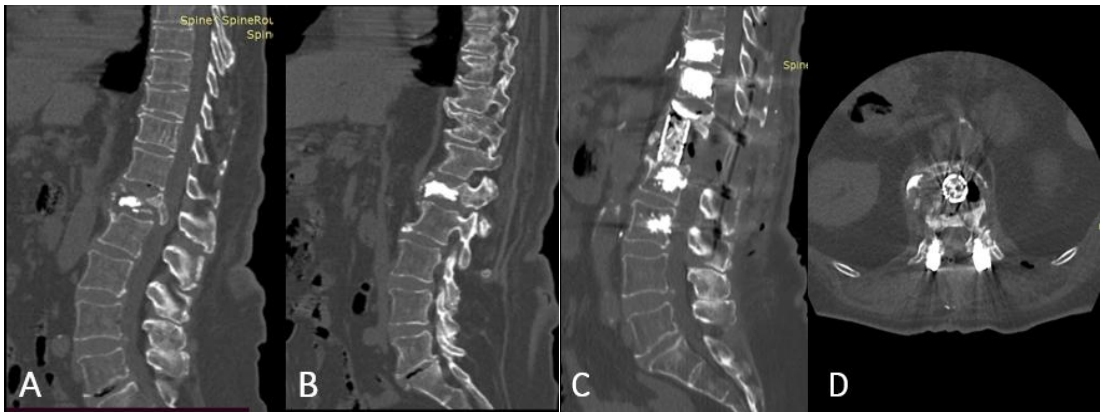

Figure 6 – Preoperative CT images demonstrating a type A3 compression fracture of the L1 vertebral body with spinal cord compression (A, B). Postoperative CT scans obtained on postoperative day 1(C, D)

Minimally invasive techniques for vertebral body reinforcement, such as vertebroplasty and kyphoplasty, have become widely adopted in the treatment of osteoporotic compression fractures, particularly in elderly patients. These image-guided procedures are performed percutaneously via a transpedicular approach and allow for effective spinal stabilization without the need for open surgery. Initially introduced for the management of vascular spinal tumors—specifically vertebral hemangiomas—these techniques were later successfully adapted to alleviate pain associated with osteoporotic fractures and to prevent further vertebral body collapse [39]. Under real-time imaging guidance (fluoroscopy or CT navigation), a cannulated needle is inserted into the affected vertebra, through which polymethylmethacrylate (PMMA) bone cement is slowly injected. The cement infiltrates the trabecular bone and hardens, stabilizing the fracture site. This process leads to rapid pain relief by reducing micromotion and restoring the vertebral body's axial load-bearing capacity [38, 39].

Kyphoplasty modifies traditional vertebroplasty by introducing an inflatable balloon prior to cement injection. Surgeons insert the balloon into the vertebral body and carefully inflate it to partially restore vertebral height and morphology, reduce kyphotic deformity, and create a contained cavity for safer cement delivery. After removing the balloon, they fill the cavity with high-viscosity cement under low pressure, which significantly lowers the risk of extravasation beyond the vertebral body. Both techniques reinforce structurally weakened vertebrae, relieve pain, stabilize the axial spinal column, and improve patient mobility and quality of life. Clinical studies and practical experience consistently support the safety and effectiveness of vertebroplasty and kyphoplasty in treating osteoporotic vertebral compression fractures, especially in patients without

neurological deficits or severe segmental instability. Figure 7 presents a clinical example demonstrating successful use of this approach in a patient with an osteoporotic fracture complicated by spinal deformity and pain.

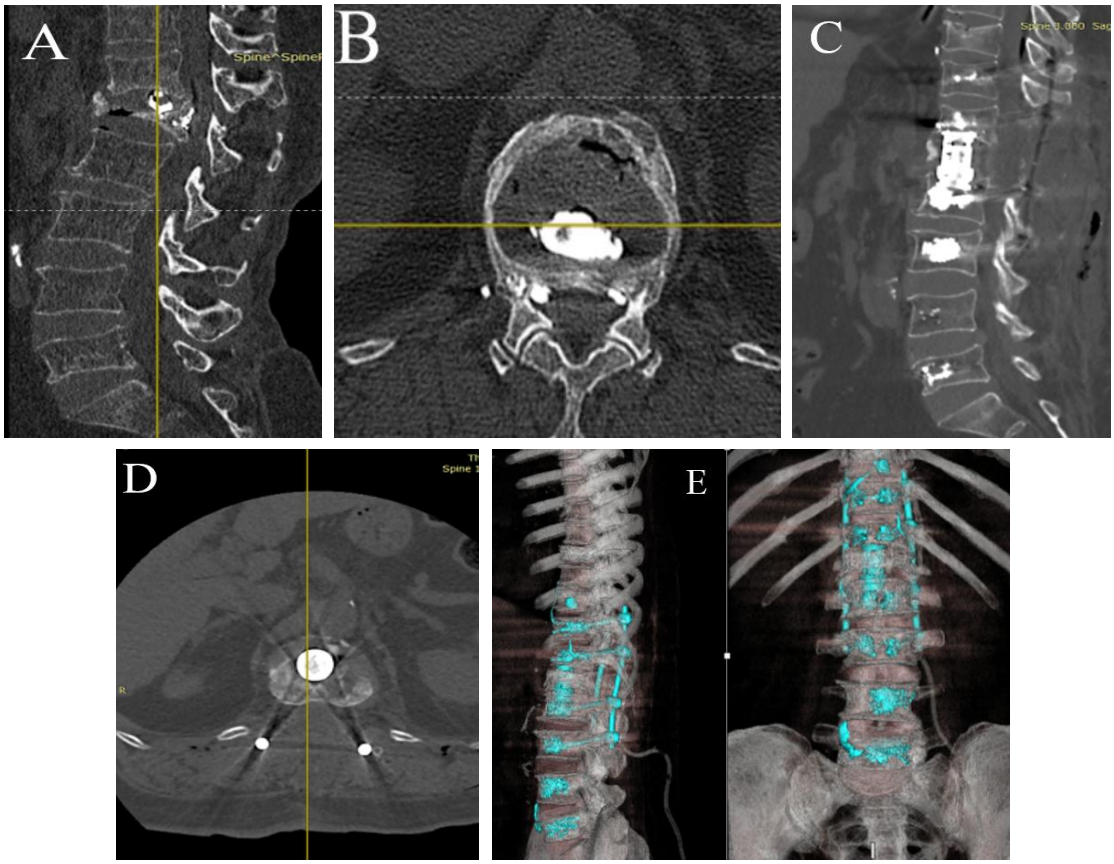

Figure 7 – Preoperative CT scans of a patient with a pathological vertebral fracture due to osteoporosis in the remote period after vertebroplasty (A, B). Postoperative CT scans obtained on day 2 following revision surgery (C, D, E). (Image from the author's personal archive)

Extensive clinical research and guidelines from leading professional organizations confirm that vertebroplasty and kyphoplasty are safe, effective, and evidence-based treatment options for patients with symptomatic osteoporotic or neoplastic vertebral fractures, provided that proper indications and procedural standards are followed [32].

These interventions are particularly appropriate in cases where conservative treatment fails to adequately control pain, leading to reduced mobility, deterioration of general condition, and diminished quality of life. Due to their minimally invasive nature, rapid recovery, and high likelihood of clinical improvement, vertebroplasty and kyphoplasty remain valuable tools in the management of compression fractures associated with systemic osteoporosis.

4. Discussion

A review of the literature indicates that surgical treatment of osteoporotic vertebral body fractures presents a number of biomechanical, technical, and prognostic challenges, requiring a comprehensive and individualized approach to the selection of stabilization methods. All current techniques offer both advantages and limitations, which depend on bone quality, the anatomical level of the lesion, and specific clinical indications.

Open transpedicular fixation remains the standard approach in cases of severe instability, spinal canal stenosis, or multilevel deformity. However, in elderly patients with osteoporosis, this technique is associated with a high complication rate. The most common complications include screw loosening, nonunion

(pseudarthrosis), and proximal junctional kyphosis (PJK), which has been reported in up to 39% of cases involving long-segment constructs [17]. Extending the fixation span and incorporating additional stabilizing elements, such as hybrid constructs, may partially reduce these risks but at the cost of increased invasiveness and additional stress on adjacent segments [21]. Furthermore, the mechanical strength of conventional screws remains limited in osteoporotic bone due to reduced thread engagement with the trabecular structure [22-24].

Expandable pedicle screws represent a logical evolution in improving implant anchorage without the need for cement augmentation. These screws have demonstrated superior pullout resistance and compressive stability through mechanical expansion within the trabecular bone following insertion [33]. They are particularly beneficial in patients with severe osteoporosis for whom cement use is undesirable. However, their widespread adoption is limited by high cost, lack of universality, and technical difficulties during implant removal. Additionally, the current literature lacks sufficient long-term follow-up data to definitively recommend these devices as a first-line option.

Minimally invasive techniques vertebroplasty and kyphoplasty have demonstrated high efficacy in the treatment of stable osteoporotic compression fractures without neurological deficits. Their primary advantages include rapid pain relief, restoration of mobility, and a low invasiveness profile [38, 39]. Kyphoplasty offers additional control over vertebral body deformation through the use of an inflatable balloon. However, both procedures have limitations in cases of instability, significant kyphosis, or neural compression, where they fail to provide sufficient segmental stabilization [3, 27].

In this context, cement augmentation remains one of the most effective strategies for enhancing fixation strength. Randomized trials have shown that vertebral body cementation increases pedicle screw pullout strength by a factor of 2 to 5 and helps maintain construct stability even in the presence of low bone mineral density [30, 35]. The use of cannulated, fenestrated screws for intravertebral cement delivery has proven effective in reducing micromotion and preventing screw failure [4, 32]. Nevertheless, this technique requires strict adherence to procedural protocols, as the main concern lies in the risk of cement extravasation into venous structures or the spinal canal, which may lead to embolic complications [31].

Several studies have demonstrated that the optimal strategy for managing unstable osteoporotic fractures involves combining transpedicular fixation with cement augmentation of the screws and/or vertebral bodies. This approach provides high biomechanical stability, reduces the risk of screw loosening—particularly in the lumbar spine and lowers the likelihood of adjacent-level kyphotic deformity when the fixation termination level is appropriately planned [6, 30]. Comparative studies have shown that short constructs involving four vertebrae, when supported by cement augmentation, offer stabilization outcomes comparable to those of traditional long-segment constructs, while also resulting in fewer surgical complications, reduced intraoperative blood loss, and shorter operative times [26, 12].

From the perspectives of effectiveness, safety, and accessibility, cement-augmented transpedicular fixation currently represents one of the most rational and balanced surgical options for treating osteoporotic fractures—particularly in elderly patients with significantly reduced bone mineral density. When combined with minimally invasive techniques, such as vertebroplasty at the affected level, this method further enhances construct stability while minimizing surgical trauma [35].

However, surgical intervention alone is not sufficient to ensure long-term clinical success. Comprehensive treatment must also include osteoporosis-targeted pharmacotherapy and structured rehabilitation. A multidisciplinary approach remains the only reliable strategy to reduce the risk of recurrent fractures, improve patient quality of life, and minimize disability in this high-risk population [8, 5].

5. Conclusions

Osteoporosis significantly complicates the surgical management of spinal disorders by increasing the risk of instability and postoperative complications. This necessitates the adaptation of stabilization strategies based on bone quality. Contemporary techniques—including cement augmentation, expandable and fenestrated screws, and minimally invasive procedures—have improved fixation reliability and clinical outcomes. The growing number of surgeries for osteoporotic fractures reflects not only the increasing prevalence of the condition but also advancements in surgical technology. Combined approaches, such as

transpedicular fixation with vertebroplasty, have proven effective in reducing construct failure, particularly in elderly patients with severe osteoporosis. Percutaneous techniques for stable fractures demonstrate clinical outcomes comparable to those of open surgery while offering lower surgical morbidity. However, no technique can be considered complete without achieving stable spinal fusion. Only the integration of surgical, pharmacological, and rehabilitative strategies can ensure safe and long-term recovery in patients with osteoporotic spinal pathology.

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Остеопоротикалық омыртқа сынықтарының хирургиялық емдеуінің заманауи стратегиялары. Әдебиетке шолу

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Түйіндіме

Омыртқа денесінің патологиялық, остеопороздық сынықтары егде жастағы науқастарда жиі кездесетін және клиникалық жағынан күрделі асқынулардың бірі болып табылады. Сүйек тінінің минералдық тығыздығының төмендеуі омыртқа құрылымдарының тұрақтылығын төмендетіп, операциядан кейінгі механикалық тұрақсыздық қаупін арттырады. Бұл шолу PubMed, Scopus және Web of Science дерекқорларында 2015 жылғы қаңтар мен 2025 жылғы сәуір аралығында жарияланған зерттеулерді талдайды. Шолу құрамына остеопоротикалық омыртқа сынуын хирургиялық емдеуге арналған түпнұсқалық мақалалар, рандомизацияланған бақылаулы зерттеулер, мета-талдаулар және жүйелі шолулар енгізілді.

Қазіргі заманғы хирургиялық тәсілдер остеопоротикалық омыртқа патологиясы бар науқастарда фиксацияның беріктігін арттыруға және клиникалық нәтижелерді жақсартуға бағытталған. Бұл шолуда цементпен күшейтілген транспедикулярлық бұрандалар, кеңейтілетін және тесігі бар имплантар, кортикальды траектория бойымен орнатылатын жүйелер, сондай-ақ вертебропластика мен кифопластика сияқты кіші инвазивті әдістер қарастырылады.

Әдеби деректер көрсеткендей, сүйек цементін қолдану бұрандалардың беріктігін едәуір арттырып, асқынулардың жиілігін азайтады. Кифопластика деформацияны түзетуге және ауырсынуды азайтуға тиімді мүмкіндік береді.

Хирургиялық тактиканы жоспарлауда сүйек сапасы мен анатомиялық ерекшеліктерді ескеретін жекелендірілген тәсілдің маңыздылығы атап өтіледі. Мұндай көзқарас қайталама операциялардың алдын алуға және ұзақ мерзімді тұрақтылықты қамтамасыз етуге мүмкіндік береді.

Түйін сөздер: остеопороз, омыртқаның патологиялық сынуы, транспедикулярлық бекіту, цементтік аугментация, кеңейетін бұрандалар, кифопластика, вертебропластика.

Современные стратегии хирургического лечения остеопоротических переломов позвоночника. Обзор литературы

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Резюме

Остеопоротические переломы тел позвонков являются одними из наиболее частых и клинически значимых последствий системного остеопороза, особенно у пациентов пожилого возраста. Снижение минеральной плотности костной ткани ухудшает стабильность спинальных фиксаторов и повышает риск послеоперационной конструктивной несостоятельности. В рамках обзора проанализированы исследования, опубликованные в базах данных PubMed, Scopus и Web of Science за период с января 2015 по апрель 2025 года. Включены оригинальные статьи, рандомизированные контролируемые исследования, метаанализы и систематические обзоры, посвященные хирургическому лечению остеопоротических переломов позвоночника.

Обзор освещает современные хирургические подходы, направленные на повышение прочности фиксации и улучшение клинических результатов у пациентов с остеопоротическим поражением позвоночника. Особое внимание уделяется применению транспедикулярных винтов с цементной аугментацией, расширяемых и фенестрированных имплантатов, систем с опорой на кортикальные структуры, а также малоинвазивных вмешательств, таких как вертебропластика и кифопластика.

Данные литературы демонстрируют, что введение костного цемента существенно повышает удерживающую способность винтов и снижает риск послеоперационных осложнений. Кифопластика дополнительно позволяет корректировать деформации и эффективно купировать болевой синдром.

Обоснована необходимость индивидуализированного хирургического планирования с учетом качества костной ткани и анатомических особенностей поражения. Такой подход критически важен для снижения вероятности повторных операций и обеспечения долгосрочной стабилизации позвоночника.

Ключевые слова: остеопороз, патологический перелом позвоночника, транспедикулярная фиксация, цементная аугментация, расширяемые винты, кифопластика, вертебропластика.