Clinical Neurology and Neurosurgery 180 (2019) 40–47

Contents lists available at ScienceDirect

Clinical Neurology and Neurosurgery

journal homepage: www.elsevier.com/locate/clineuro

Clinical considerations for spinal surgery in the osteoporotic patient: A comprehensive review

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ARTICLE INFO

Keywords:
Osteoporosis
Osteopenia
Spine surgery
DEXA
Spinal instrumentation

ABSTRACT

Osteoporosis is a skeletal condition characterized by low bone mineral density (BMD). Common in older patients undergoing spinal fusion, it is a significant risk factor for instrumentation failure and related complications. The objective of this review is to articulate clear suggestions for screening and medical/surgical management strategies in patients with osteoporosis. A thorough review of the literature was conducted using PubMed. Varied search terms were applied to yield published manuscripts on osteoporosis and spine surgery. Biomechanical studies and studies conducted in animal models were excluded. Screening should be considered in those that present with multiple risk factors for low BMD. Dual-energy x-ray absorptiometry (DEXA) remains the gold standard, but Hounsfield Units (HU) have emerged as a powerful complement to DEXA. While both bisphosphonates and teriparatide have been investigated in the perioperative setting and have a positive impact on outcomes, teriparatide maintains an advantage in comparative studies. Surgical treatment need not be postponed. Standard surgical modifications such as using multiple points of fixation, varied fixation equipment, anterior/posterior instrumentation, and modified screw design/trajectories should all be considered. However, recent clinical studies focus on cement augmentation and expandable pedicle screws. All have been shown to improve bone-screw interface strength, but extravasation remains a risk of cement augmentation, and hydroxyapatite cement (HAC), while an emerging alternative to polymethyl methacrylate (PMMA), is not as well investigated in the setting of osteoporosis. Furthermore, research on expandable pedicle screws is limited. To conclude, optimizing spine surgery outcomes in the osteoporotic patient is possible with a thorough preoperative workup, medical management, and a tailoring of the surgical technique. This is especially important when performing complex spinal instrumentation.

1. Introduction

Osteoporosis is a skeletal condition characterized by low bone mineral density (BMD), leading to decreased bone strength and increased risk of fracture. According to one estimate, some 10.3%, or 10.2 million American adults over the age of 50 have osteoporosis. An even higher 43.9%, or 43.4 million have osteopenia or low bone mass. There is a sharp increase in low BMD with increasing age, and the condition is more common in females [1]. The World Health Organization (WHO) defines the criteria used to diagnose this condition based on T-score, a statistic derived from dual energy x-ray absorptiometry (DEXA). T-score is equal to the number of standard deviations a patient's BMD is above or below mean BMD in a healthy, 30 year old adult. T-score ≤ -2.5 corresponds to osteoporosis, and T-score between -2.5 and -1.0 corresponds to low bone mass (osteopenia).

Osteoporosis and low bone mass are especially relevant to spinal surgery. Spinal instrumentation requires healthy bone stock, and poor bone quality is associated with fracture, pseudarthrosis, instrumentation failure, adjacent level disc degeneration, and progressive kyphosis [2]. Given the number of older patients with low BMD and the increasing age of the population undergoing spinal instrumentation, providers need to consider bone quality more carefully than ever.

Abbreviations: BMD, bone marrow density; DEXA, dual energy x-ray absorptiometry; WHO, World Health Organization; HU, Hounsfield units; PLF, posterolateral fusion; LIF, lateral interbody fusion; rPTH, recombinant parathyroid hormone; ODI, Oswestry disability index; PSL, pedicle screw loosening; VAS, visual analogue score; TLIF, transforaminal lumbar interbody fusion; PMMA, polymethylmethacrylate

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https://doi.org/10.1016/j.clineuro.2019.03.010
Received 2 January 2019; Received in revised form 4 March 2019; Accepted 10 March 2019
Available online 11 March 2019
0303-8467/

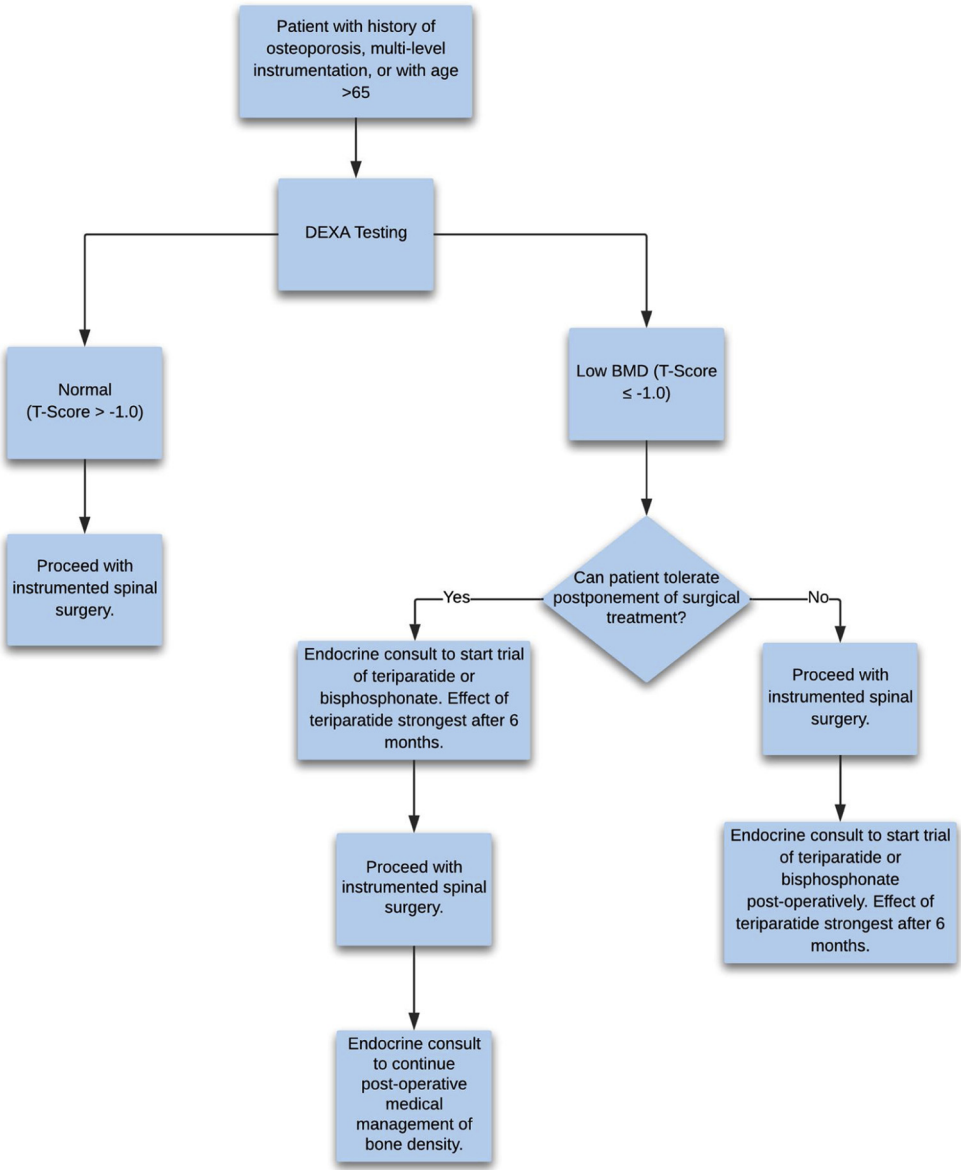

Fig. 1. Screening and treatment algorithm. Note that Kim et al. found increased effect of teriparatide after six months [26]. Chart produced with Lucidchart online tool.

Furthermore, there is no standard clinical approach to screening for and treating patients with low BMD. The objective of this review is to articulate clear suggestions for providers regarding the consideration of BMD in the presurgical setting and to communicate the most appropriate medical and surgical management strategies for those patients with low bone density. A thorough review of the literature was conducted using PubMed. Varied search terms were applied to yield published manuscripts on osteoporosis and spine surgery, with a focus on clinical outcomes studies. Biomechanical studies and studies conducted in animal models were excluded. These findings should help to bring clarity to the perioperative management of low BMD.

2. Screening

Routine assessment and screening for decreased BMD in the presurgical setting is critical and can help guide the pre and postoperative treatment course (Fig. 1). Chin et al found that among patients over the age of 50 undergoing spinal instrumentation at a single center, 51.3% of females and 14.5% of males had T-scores consistent with osteoporosis. Another 41.4% and 46.1% had T-scores consistent with low bone mass [3]. At the same institution, the average age of patients undergoing spinal surgery increased from 40.5 to 51.5 between 1995 and 2005. Assuming that this trend has continued, the proportion of patients undergoing spinal procedures with inadequate BMD is sure to have increased, and these patients must be identified so that the provider can adjust the patient's treatment plan accordingly.

Meanwhile, as few as 44% of surgeons report ordering DEXA when osteoporosis is suspected. Of those, 74% report that the results of this testing affect their treatment and/or surgical plan [4]. Other studies corroborate these findings. For instance, using Hounsfield Units (HU) derived from lumbar CT scans, Wagner et al found that just 36% of patients with HU values consistent with osteoporosis had previous DEXA scans on record. Further, just 40% were treated for low BMD. An even smaller proportion of those with low bone mass were tested and treated [5]. Given these findings, patients being considered for instrumented spinal fusion or reconstruction should be evaluated for osteoporosis. The most significant risk factors for osteoporosis are age and sex, and the disease is most common in older, postmenopausal females. However, there are a number of other significant risk factors that fall into the following categories: medications, endocrine disorders,

rheumatologic disorders, and malabsorptive conditions [6,7]. Patients with multiple risk factors should be considered for additional testing.

DEXA scans remain the gold standard for diagnosing osteoporosis due to its wide availability, low cost, and low associated radiation exposure. However, the test has some limitations that providers should be aware of. For example, in patients with degenerative spinal changes, fractures in lumbar vertebrae, and scoliosis or aortic calcification, DEXA at the posteroanterior spine might show falsely elevated BMD values. In this case, scans obtained from other anatomic locations might be more reliable [8]. On the other hand, Mounach et al observed that of 1603 patients with discordance between hip and spine diagnoses based on BMD, 1390 patients had lower measured lumbar BMD. In addition, significant odds ratios for minor discordance (normal vs. osteopenia or osteopenia vs. osteoporosis) were found for age > 50 years old, history of osteoporotic fracture, and menopause. Significant odds ratios for major discordance (normal vs. osteoporosis) were found for age > 50 years old, BMI > 30 kg/cm^2, and menopause [9]. Therefore, care must be taken to choose the most appropriate test site in order to obtain an accurate measurement of global BMD.

More recently, Hounsfield Units (HU), obtained from a linear transformation of the measured attenuation coefficient on a CT scan, have emerged as a possible surrogate measure for BMD. Multiple studies have shown a correlation between HU values and T-score or BMD. Schreiber et al observed that trabecular HU values in 25 patients had a moderate but significant correlation with T-score (r^2 = 0.48, $p < 0.0001$) and areal BMD (r^2 = 0.44, $p < 0.0001$). Furthermore, in a polyurethane foam model, a strong correlation was found between material density and HU value (r^2 = 1.0, $p < 0.0001$), and between HU value and elastic modulus (r^2 = 0.998, $p < 0.0001$) [10]. Although this sample was limited to patients with osteoporosis or spinal trauma, the result has been replicated. In a sample of 128 female patients that underwent CT for low back pain, Lee et al observed that trabecular HU were significantly correlated with T-score (L1-L4 r^2 values were 0.673, 0.794, 0.766, and 0.713, respectively; $p < 0.001$ for all vertebrae) and areal BMD (L1-L4 r^2 values were 0.657, 0.774, 0.737, 0.673, respectively; $p < 0.001$ for all vertebrae) [11]. Choi et al found a similar result. In 80 non-degenerative patients, there was a significant correlation between HU and T-score of the L1-L4 vertebrae (r^2 = 0.734, $p < 0.001$). However, in 30 degenerative patients, the strength of that relationship deteriorated (r^2 = 0.398, p = 0.031) [12]. Thus, while HU might be a useful surrogate measure for T-score and BMD, results should be evaluated with care in those patients with extensive degeneration.

Recent studies have also shown that HU might help to predict surgical outcomes and complications after spinal procedures. Meredith et al found that 20 patients with adjacent segment fracture after spinal fusion had lower global HU (139.9 vs. 170.1, p = 0.032), and lower HU at the level of the fracture (145.6 vs. 199.4, p = 0.006) compared to non-fracture controls [13]. Nguyen et al found that 10 patients requiring revision for symptomatic pseudarthrosis after posterolateral fusion (PLF) had lower HU values compared to those that didn't require revision. However, while the difference between pooled L4-L5 HU values reached significance (p = 0.01), the difference between pooled L1-L3 HU values did not (p = 0.13) [14]. Another study by Schreiber et al found that patients with successful union after lateral interbody fusion (LIF) had higher global HU (203.3 vs. 139.8, $p < 0.001$), and higher HU at the operated level (133.7 vs. 107.3, $p < 0.05$) than those with nonunion [15].

In conclusion, routine assessment and screening for osteoporosis in the presurgical setting is needed as the average age increases for the patients undergoing spinal instrumentation. A significant number of patients undergoing spinal surgery have osteoporosis. However, an insufficient number of surgeons order additional testing for patients suspected to have inadequate BMD. As a result, many patients that undergo spinal surgery have undiagnosed osteoporosis. If patients have multiple risk factors for osteoporosis, additional testing should be ordered. DEXA remains the gold standard, but has some limitations. HU values are not a replacement for DEXA, but are correlated with areal BMD and T-score, especially in patients without degeneration. HU values also help predict surgical outcome if spinal CT has already been performed.

3. Treatment

Pharmacological treatments for osteoporosis can be divided into the following categories: calcium and vitamin D supplementation, bisphosphonates, recombinant parathyroid hormone (rPTH), estrogen and selective estrogen receptor modulation, calcitonin, and most recently, RANK ligand inhibitors such as denosumab. However, only bisphosphonates and rPTH have been studied in the perioperative setting (Table 2). Bisphosphonates such as alendronate are anti-catabolic agents that induce osteoclast apoptosis, reducing the breakdown of bone. There is only one available form of rPTH, teriparatide, an anabolic agent that exerts a net positive effect on bone growth, activating osteoblasts more than osteoclasts.

3.1. Bisphosphonates

There has been some disagreement as to whether or not the adverse impact of bisphosphonates on the biological healing process has a negative impact on surgical outcomes. As measured by bone alkaline phosphatase and N-terminal telopeptide, Nagahama et al showed decreased bone growth at six months post-op and decreased bone resorption at each follow-up with once per week alendronate after posterior lumbar interbody fusion (PLIF) compared to vitamin D control in a sample of 40 total patients. However, overall fusion rate at 12 months post-op was higher (95% vs. 65%, p = 0.025), and risk of vertebral compression fracture (VCF) was lower in the treatment group (0% vs. 24%, p = 0.027). On the other hand, there was no significant difference in clinical outcomes measured by Oswestry Disability Index (ODI) scores at follow up [16]. Kim et al failed to replicate this result, finding no difference in fusion rate (p = 0.599) between alendronate and control in patients with and without endplate degeneration after PLF in a sample of 44 total patients [17].

Zoledronate, another bisphosphonate, has been more extensively studied. Park et al found no significant difference between fusion rate (p = 0.152) or volume of fusion mass (p = 0.533) between zoledronate and control groups at six months follow-up after one or two-level PLF in a sample of 44 patients. In addition, no difference in clinical outcomes was appreciated. No significant difference between complication rates was observed (p = 0.563) [18]. On the other hand, Tu et al observed higher fusion rate (75% vs. 56%), and lower risk of VCF (19% vs. 51%, p = 0.006), cage subsidence (28% vs. 54%, p = 0.04), and pedicle screw loosening (PSL) (18% vs. 45%, p = 0.03) at 24 months follow-up in patients treated with zoledronic acid. While insignificant, improvement in Visual Analogue Scores (VAS) (p = 0.2071 for leg pain VAS and p = 0.3544 for back pain VAS) was appreciated. Significant improvement in ODI (p = 0.01) was observed in the zoledronic acid group. A total of 64 patients were included [19]. It is important to note that both of these studies were limited by their retrospective model. In the first randomized, placebo-controlled, triple-blinded study examining zoledronic acid and spinal fusion in 79 patients, Chen et al found earlier fusion (significant difference at 3, 6, and 9 months, but nonsignificant difference at 12 months), reduced risk of VCF (0% vs. 17%, $p < 0.05$), and better clinical outcomes as measured with ODI at nine and 12 months post-op ($p < 0.05$), but no difference in overall fusion rate (82% vs. 83%) for patients treated with zoledronic acid. Three patients (9%) in the zoledronic acid group and five patients (14%) in the control group had fusion failure [20]. Among 30 patients receiving zoledronic acid and 34 controls, Ding et al showed similar results. No significant difference was observed between overall fusion rates at 12 months (92% vs. 92.86%, $p > 0.05$), and better clinical outcomes were

Table 1
Summary of studies investigating the use of perioperative bisphosphonates in patients with osteoporosis undergoing spinal surgery. * Denotes statistical significance.

Authors	Medication	Study Design	Total Number of Patients	Control	Fusion Rate (treatment vs. control)	Risk of Pedicle Screw Loosening (Treatment vs. Control)	Risk of Vertebral Compression Fracture (Treatment vs. Control)	Risk of Cage Subsidence (Treatment vs. Control)	Difference in Clinical Outcomes (Yes or No)
Nagahama et al. [16]	Alendronate	Prospective Study	40	Vitamin D / alfacalcidol	95% vs. 65% *		0% vs 24%		No significant difference in ODI.
Kim et al. [17]	Alendronate	Prospective Study	44	"Patients who were not taking alendronate for less than one week due to poor economic conditions." Not given other medications.	92.3% vs. 90%				
Park et al. [18]	Zoledronate	Retrospective Study	44	No medication administered.	100% vs. 91%				No significant difference in VAS, ODI, or SF-36 scores.
Tu et al. [19]	Zoledronate	Retrospective Study	64	No medication administered.	75% vs. 56%	18% vs. 45% *	19% vs. 51% *	28% vs 54% *	At 24 months, ODI scores but not VAS was significantly lower in the treatment group.
Chen et al. [20]	Zoledronate	Randomized, Placebo-Controlled, Triple-Blind	79	Placebo	82% vs 83%		0% vs 17% *		Significantly better clinical ODI scores in the treatment group at nine and 12 months.
Ding et al. [21]	Zoledronate	Retrospective Study	64	Calcium and Vitamin D (all patients received this postoperatively)	92% vs. 92.86%	0 vs. 6 cases	0 vs. 5 cases *		VAS, ODI, and SF-36 scores were significantly better in the treatment group at 12 and 24 months.

Table 2
Pharmacological Agents for Osteoporosis Perioperative Management.

Class	Medication	Action	Dosage	Length of Treatment	Risks [27,28]	Outcome
Vitamin / Mineral Supplementation	Vitamin D	Promotes calcium absorption in the intestine	Up to 800 – 1000 IU daily oral (some need more) [29]	Continuous while supplementation is required	Possible adverse events with high doses in patients that are not deficient	No studies investigating its effect on operative outcomes
	Calcium	Increases serum calcium levels and thus reduces bone resorption	Up to 1200 mg daily oral (including intake from diet) [29]		Potential increased risk of cardiovascular disease, negative effect on lipid levels, nephrolithiasis risk	No studies investigating its effect on operative outcomes
Bisphosphonates	Alendronate	Inhibits osteoclastic bone resorption	35 mg weekly oral	Suggested length of treatment in perioperative setting unclear	Atypical sub-trochanteric and femur fractures, osteonecrosis of the jaw, renal dysfunction, cardiovascular (such as atrial fibrillation) and cerebrovascular events, gastrointestinal adverse events and esophageal cancer, acute phase reaction, musculoskeletal pain, transient hypocalcemia, ocular inflammation, cutaneous manifestations (rash, itching, urticaria), mucositis / oral mucosa lesions, transient hepatitis	Unclear effect on the fusion process based on available studies [16,17]
	Zoledronate		5 mg IV infusion	Once annual dose (studied in the postoperative setting)		Earlier fusion and reduced risk of complications with improvement in clinical outcomes in some studies [19,20,21] [30]
rPTH	Teriparatide	Promotes osteoblastic bone mineralization more than it promotes osteoclastic bone resorption	20 ug per day subcutaneous	Improvement in surgical outcomes most pronounced after at least six months of treatment [26,31]	Osteogenic sarcoma, hypercalcemia	Earlier fusion, higher overall fusion rate, reduced PSL compared to bisphosphonate alone or combined therapies [22,23,24,25,26]

observed at 12 and 24 months ($p < 0.05$) in the zoledronate group on VAS, ODI, and SF-36 score scales. In addition, rates of VCF (0 vs. 5 cases, $p < 0.05$) and PSL (0 vs. 6 cases) were reduced in the treatment group [21].

Despite the adverse effect of this class of medications on the biological healing process, reducing both bone reuptake and bone growth, the evidence for use of bisphosphonates to improve surgical outcomes seems positive. Although no definitive statement can be made about overall fusion rate or clinical outcome measures, bisphosphonates induce earlier fusion, and reduce the risk of cage subsidence, VCF, and PSL [17–19]. More evidence supports the use of zoledronic acid infusion in the postoperative setting compared to alendronate, but more research needs to be conducted in order to make a more precise statement about the benefits of each medication or to make a definitive statement about the optimal dosage regimen. However, these studies demonstrate that each medication can have a role in safely improving surgical outcomes without the need to delay surgery while waiting for BMD to improve. See Table 1 for a summary of the above studies and their respective findings.

3.2. Teriparatide

Research investigating the use of teriparatide in the perioperative setting is also promising. Among 57 total patients, Ohtori et al observed earlier fusion and a higher overall fusion rate at 12 months post-op in postmenopausal women treated with teriparatide for two months pre-op and eight months post-op after one or two-level PLF as compared to risedronate control (82% vs 68%, $p < 0.05$). No significant difference in low back pain VAS (1.8 ± 0.7 vs. 2.0 ± 0.9, $p = 0.36$), low back pain ODI (22 ± 8 vs. 24 ± 4, $p = 0.20$), or leg pain VAS (1.7 ± 0.7 vs. 2.1 ± 1.0, $p = 0.15$) was observed [22]. Ebata et al found that 29 patients treated with teriparatide for six months post-op after PLF or transforaminal lumbar interbody fusion (TLIF) had a higher overall fusion rate at six months follow-up (69% vs 35.1%, $p = 0.013$) compared to 37 patients in the no-teriparatide arm. They also observed an increase in bone growth markers with a decrease in bone resorption markers. No significant difference in Japanese Orthopedic Association Pain Evaluation Questionnaires (JOA-BPEQ) or ODI scores was observed between groups [23]. With a total of 47 patients, Cho et al found that three months of teriparatide followed with three months alendronate for 12 months after PLIF led to earlier fusion (6.0 ± 4.8 months vs. 10.4 ± 7.2 months, $p = 0.006$) and improved BMD recovery range (T-score) at 24 months follow up compared to alendronate alone (0.7 ± 1.4 vs. 0.1 ± 0.5, $p = 0.013$). However, no significant difference in ODI, VAS, or Prolo scale scores was observed at 24 months, and no significant difference in overall fusion rate was appreciated (92.6% vs 96.4%, $p = 0.486$) [24]. An arm with teriparatide alone would have offered additional insight.

Two studies evaluated the effect of teriparatide on PSL compared to bisphosphonate. With a study size of 62 total patients, Ohtori et al showed a significant reduction in the incidence of PSL in postmenopausal women treated with teriparatide for two months pre-op and 10 months post-op after one or two-level PLF compared to risedronate and nonmedicated control as detected on radiographic and CT analysis (7%–13% vs. 13%–26% and 15%–25%; $p < 0.05$). Unlike other bisphosphonates, risedronate did not significantly reduce the rate of PSL [25]. Among 84 patients, Kim et al observed that the number of loosened pedicle screws at 12 months follow up after TLIF was higher in patients treated with teriparatide for six months post-op followed by risedronate (9.3% vs 16.1%, $p = 0.043$), with no difference between the number of loosened screws at six months (6.9% vs 6.8%, $p = 0.965$), or the overall rate of PSL at six (12% vs 13%, $p = 0.831$) or 12 months (18% vs 25%, $p = 0.434$) compared to risedronate-only control. However, the number of loosened screws detected between 6 and 12 months was significantly different (2.3% vs 9.2%, $p = 0.027$) [26]. This suggests that the benefit of teriparatide in reducing PSL is most significant after six months. Longer treatment and follow-up in future research efforts might reveal additional statistical significance between the groups.

Overall, teriparatide leads to earlier fusion, higher overall fusion rates in some studies, and reduced PSL compared to bisphosphonates. However, additional studies comparing different dosage regimens with nonmedicated controls are needed to optimize surgical outcomes. Despite the fact that teriparatide was shown to reduce PSL after six months, it remains to be shown whether teriparatide before the procedure would further improve surgical outcomes. If so, the effect size must be large enough to justify the delay in patients who would otherwise have immediate surgery. Nevertheless, the evidence suggests that significant improvements in surgical outcomes are possible even when treatment is not started until after the procedure. Lastly, the side effect profiles of these medications are well documented [27], and providers should be aware of the potential short and long-term effects of each before beginning treatment. See Table 1 for a summary of the above studies and their respective findings.

4. Surgical technique

Careful consideration of surgical technique in patients with low BMD is also needed in order to reduce complications and improve outcomes. A number of authors suggest using multiple points of fixation, cross linking, varied fixation equipment such as laminar hooks and wires, anterior and posterior instrumentation, modified screw design and trajectories, and other methods in order to improve fixation strength and reduce the risk of complications [18,32–39]. However, two methods for improving bone-screw interface strength have been more extensively investigated in clinical, outcomes-focused studies: cement augmentation, with and without pedicle screw fenestration, and expandable pedicle screws. Traditional cement augmentation requires that cement be injected into a pilot hole, followed by screw implantation. With pedicle screw fenestration, cement is injected through the screw, and cement pressure and flow are controlled.

4.1. Cement augmentation

In one study of cement augmentation without pedicle screw fenestration, calcium apatite cement was used in seven patients undergoing surgery for spinal deformity. PSL was observed in just one patient, with loosening in one of 16 total ventral augmented screws. Cement leakage was observed in three patients at four of 48 dorsal augmented screws [40]. In a later study, polymethylmethacrylate (PMMA) cement augmentation was performed in 41 patients undergoing surgery for spinal and foraminal stenosis, VCF or burst fracture, and tumor. No PSL was observed but cement leakage occurred in 26.2% of screws. Significant improvements in VAS (9.2 ± 2.3 vs. 1.5 ± 2.0, $p < 0.01$) and ODI scores (77.5 ± 19.3 vs. 44.2 ± 19.0, $p < 0.01$) were appreciated [41]. Aydogan et al utilized PMMA cement augmentation, and performed prophylactic vertebroplasty in one segment proximal and distal to the fused region in 36 patients. One patient had PSL, but no cement extravasation or adjacent segment fracture were observed. However, one pulmonary embolism due to cement did occur [42]. Low incidence of extravasation was likely due to reduced volume of injected cement. Kim et al demonstrated that 62 patients undergoing vertebroplasty at fused levels after single level anterior lumbar interbody fusion (ALIF) had reduced risk of cage subsidence (5.2% vs 19.6%, $p = 0.001$) and vertebral body collapse (3.9% vs 10.7%, $p < 0.001$), but this result produced no difference in clinical outcomes based on VAS and ODI scores [43].

Hydroxyapatite cement (HAC) has been studied as an alternative to PMMA. However, studies investigating its use in the setting of patients with osteoporosis are limited. Jang et al investigated HAC screw augmentation in 34 patients with osteoporosis undergoing spinal surgery with spondylolisthesis grade I or II at L4-L5. Patients in the treatment

group underwent TLIF with polyethyetherketone (PEEK) cages and HAC augmentation. Those in the control underwent traditional TLIF. Patients in the treatment group had higher overall rate of fusion (93.8% vs 76.2%), but this did not reach statistical significance ($p = 0.089$). Those in the control exhibited a significant increase in all five radiological criteria measured in the study between postoperative day 1 and 24 months. Those included segmental lordosis (2.8 ± 2.1, $p = 0.003$), disc height (3.2 ± 1.7, $p = 0.003$), screw angle (3.2 ± 2.5, $p = 0.005$), L4 screw angle (1.3 ± 1.7, $p = 0.044$), and L5 screw angle (1.8 ± 1.8, $p = 0.019$). No significant increase in these parameters was observed in the treatment group at either 3 months or 2 years after surgery. Low back pain VAS scores were lower in the treatment group at 2 years follow up (1.01 ± 1.42 vs. 2.19 ± 1.23), but this difference did not reach statistical significance ($p = 0.107$). No major complications occurred in either group [44]. While these results suggest that HAC augmentation has the potential to be safe and effective in patients with osteoporosis, it offers no direct comparison to PMMA. Additional research is needed.

Fenestrated pedicle screws also improve bone-screw interface strength, but their effect on extravasation remains unclear. In 37 patients with progressive spinal deformity receiving PMMA augmentation with fenestrated pedicle screws, Bong et al observed an overall fusion rate of 91.9%, with local cement extravasation in two out of 37 patients, and PSL in one. Significant improvement in low back pain VAS (7.87 ± 0.95 vs. 2.30 ± 1.61, $p = 0.006$), leg pain VAS (8.82 ± 0.83, $p = 0.003$), and mean Prolo score (4.22 ± 0.95 vs. 7.76 ± 1.74, $p = 0.001$) was observed [45]. In 23 patients over the age of 70 with degenerative lumbar stability, Piñera et al observed 74% radiographic fusion, and 100% fusion on CT at 6 months follow up, with no pullout, hardware failure, or adjacent segment fracture. However, adjacent segment degeneration was observed in 17% of patients, and extravasation at 29.3% of augmented vertebrae. A total of 90% of patients had an improvement of ≥ 15 points on the ODI scale [46]. Amendola et al also observed 100% fusion in 21 patients without tumor at six months follow up, with no PSL or screw pullout, but observed intraoperative and postoperative extravasation in two and three out of 21 patients. Significant improvements in all measured SF-36 batteries (all $p < 0.001$) and VAS score (8.2 vs. 1.7, $p < 0.001$) were observed [47]. With a modified fenestrated pedicle screw and PMMA augmentation, Dai et al found that none of the 43 patients with degenerative lumbar disease required reoperation for nonunion, and observed no PSL, screw pullout or fracture. Extravasation occurred in four patients [48].

4.2. Expandable pedicle screws

Research investigating expandable pedicle screws is less widespread, but promising. Cook et al observed an overall fusion rate of 86% in 21 patients with osteoporosis when expandable pedicle screws were used to enhance bone-screw interface strength, with no PSL or screw pullout, and one patient with screw breakage [49]. In another study, fusion was observed in 92.8% of 125 patients undergoing surgery for degenerative disease, vertebra fracture, spinal tuberculosis, and re-operation. No PSL, screw pullout, or screw breakage were observed. JOA score improved from 11.3 ± 3.0 to 25.2 ± 2.0, and VAS score improved from 6.7 ± 1.8 to 2.3 ± 1.7 [50]. Gazzeri et al found similar results in 33 patients undergoing surgery for traumatic or degenerative spinal diseases, with one case of screw migration/breakage at 24 month follow-up. Clinical success, which was defined in the study as ODI score improvement greater than 25%, VAS score improvement of more than 2 points, recovery rate greater than 50%, and no major complications related to the implant, was observed in 93.9% of patients [51]. These results provide strong evidence for the safe and effective use of expandable pedicle screws in spinal fusion.

Although cement augmentation with and without fenestrated pedicle screws has produced strong clinical outcomes, the advantage of fenestrated screws as it relates to cement extravasation is not clear. Additional research comparing augmentation with and without fenestrated screws, or investigating alternative cements such as HAC can provide additional insight. However, procedures using fenestrated screws have had a consistently strong, positive effect on fusion, with low associated equipment failure. That being said, the risks of cement extravasation cannot be ignored. Although a significant number of the cases reported in the literature were asymptomatic, or their associated complications disappeared with conservative treatment, patients should be monitored carefully for embolism and other complications. Research investigating expandable pedicle screws is limited, but shows consistent evidence of strong fusion with limited risk of complications. Additional controlled trials and trials comparing expandable pedicle screws and cement augmentation are needed to make a more definitive statement.

4.3. Hydroxyapetite coated pedicle screws

Hydroxyapetite coated (HC) pedicle screw technology emerged with the goal of improving purchase and decreasing screw loosening. The results in animal models have been promising [52]. A dearth of clinical studies, however, has mitigated the enthusiasm of wide adoption of this technology. In one study assessing 23 patients who had partial or fully coated HA screws versus “bare” screws implanted during lumbar fusion, Sanden et al demonstrated improved fixation and less loosening with the HA coated screws as measured by extraction torque [53]. Whether the reasons were cost, lack of clinical studies or availability of cement-augmentation technology, HA coated pedicle screws have likely fallen out of favor in osteoporotic patients needing better immediate fixation.

5. Conclusions

Osteoporosis will continue to be an increasingly prevalent surgical comorbidity. Therefore, providers considering spinal instrumented surgery in older patients should consider BMD in their standard workup. Our recommendations for screening and treatment are included in Fig. 1. If multiple risk factors for osteoporosis are present, DEXA should be considered. DEXA does, however, have some limitations, and the provider should be aware that spinal BMD can be overestimated if degenerative changes are present. Therefore, multiple anatomic locations should be tested. QCT is not a replacement for DEXA, but if available, HU values can help to predict the risk of surgical complications such as cage subsidence, fracture, and nonunion.

If DEXA reveals that the patient has osteoporosis, bisphosphonate or teriparatide treatment can be initiated. Existing evidence supports the use of teriparatide over bisphosphonate. Researchers have observed a significant improvement in surgical outcomes when treatment begins immediately after surgery. Therefore, surgery should not be delayed in patients for whom conservative treatments have failed, and repeat DEXA is not required. However, the effect of teriparatide is most apparent after six months of treatment, so it can be considered in the presurgical setting if conservative treatment is tolerated.

Surgical considerations should include techniques such as multiple points of fixation, cross linking, varied fixation equipment such as laminar hooks and wires, anterior and posterior instrumentation, modified screw design and trajectories, and other methods which will improve fixation strength and reduce the risk of equipment failure. However, clinical, outcomes-focused research is limited and is currently focused on cement augmentation and expandable pedicle screws. The utility of HAC as an alternative to PMMA remains unclear and should be a focus of future research in this area.

Disclosures

The authors have no disclosures.

Declarations of interest

none

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

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