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Role of Cement-Augmented Pedicle Screws in the Osteoporotic Spine

Biomechanics, indications, techniques, outcomes, complications, and contemporary bone-health strategy

Cement augmentation is a powerful local solution for a weak bone–implant interface. It should be targeted to the fixation problem, delivered with leakage-conscious technique, and combined with systemic osteoporosis treatment and construct-level risk reduction.

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Abstract: ***Osteoporosis reduces pedicle screw fixation strength and increases loosening, pullout, pseudarthrosis, junctional failure, and revision risk. Polymethylmethacrylate (PMMA) augmentation increases the screw–bone contact area and improves pullout and cyclic fatigue resistance. Contemporary evidence- largely observational and heterogeneous- shows substantially lower screw-loosening rates and, in degenerative lumbar cohorts, higher fusion rates than conventional screws. A 2023 meta-analysis of 12 studies (881 patients) reported lower loosening with augmentation (odds ratio 0.13) and higher fusion (odds ratio 2.80). A 2026 meta-analysis in osteoporotic lumbar spondylolisthesis similarly found lower loosening (odds ratio 0.18) and higher fusion (odds ratio 3.98), with longer operating time. Benefits must be weighed against cement leakage, pulmonary cement embolism (PCE), thermal or neural injury, infection, difficult revision, and stress concentration. A complication meta-analysis reported any leakage in 21.8%, symptomatic leakage in 1.2%, PCE in 3.0%, and symptomatic PCE in 0.8%; detection rises with routine postoperative CT. Fenestrated screws provide controlled post-insertion injection and favorable cement distribution, whereas pre-injection around solid screws is versatile but more dependent on cement timing and screw insertion. Patient selection should integrate dual-energy X-ray absorptiometry, opportunistic CT Hounsfield units, fracture history, construct length, junctional risk, and intraoperative purchase. Cement should be used selectively at mechanically critical levels, with low-pressure fluoroscopic injection of the minimum effective volume. It complements—but does not replace- anabolic therapy, calcium/vitamin D correction, alignment goals, robust pelvic fixation, interbody support, and proximal-junctional protection.***

Keywords: osteoporosis; cement augmentation; pedicle screw; fenestrated screw; PMMA; screw loosening; pulmonary cement embolism; spinal fusion

1. Introduction

The aging spine-surgery population has made poor bone quality a central determinant of fixation failure. Osteoporotic cancellous bone provides reduced thread purchase; cyclic toggling creates a radiolucent halo and progressive loosening, while long constructs add cantilever and junctional loads. The resulting failure spectrum includes pullout, subsidence, loss of correction, pseudarthrosis, proximal or distal junctional failure, and revision.

Cement augmentation addresses the local interface by interdigitating PMMA with trabecular bone around the screw. It is one component of a broader strategy: identify and treat metabolic bone disease, reduce construct stress, improve anterior-column support, choose anchors intelligently, and plan the junctions. The key question is not whether cement improves purchase—it does- but which patients, levels, technique, volume, and cement state provide the best benefit–risk ratio.

1) Assessment of bone health

Patients at risk should undergo structured assessment rather than relying on tactile impression alone. The 2021 Congress of Neurological Surgeons guideline supports preoperative testing with dual-energy X-ray absorptiometry (DEXA), CT Hounsfield units (HU), or vitamin D; low BMD predicts adverse events. Degenerative change can falsely elevate lumbar DEXA, so hip/forearm sites, vertebral fracture assessment, and opportunistic CT may be more informative. AO Spine recommendations published in 2025 emphasize routine osteoporosis evaluation in adult deformity and perioperative anabolic treatment when feasible.

Table 1: Bone-health assessment should combine imaging, clinical risk, and operative findings

Measure	Interpretation for fixation planning	Caveat
DEXA	T-score ≤ -2.5 supports osteoporosis; hip/forearm can guide diagnosis	Lumbar degeneration, aortic calcification, and prior instrumentation may artifactually elevate BMD
CT HU	Low vertebral HU predicts loosening, junctional failure, and pseudarthrosis risk	Scanner/protocol and level matter; no single universal cutoff
Clinical history	Fragility fracture, age, steroids, low BMI, smoking, malnutrition increase risk	Risk can be high despite non-osteoporotic DEXA
Intraoperative purchase	Low insertional torque or poor tactile purchase may trigger selective augmentation	Subjective; should not replace preoperative assessment

2) Biomechanical rationale and materials

PMMA creates a composite fixation mass that enlarges the load-transfer surface beyond the screw threads. Cadaveric and synthetic-bone studies generally show approximately twofold improvements in pullout strength, with reported gains varying by BMD, screw design, cement distribution, and test method. Cyclic fatigue resistance is at least as relevant as axial pullout because clinical loosening often occurs through repetitive toggling.

Benefit is greatest in low-density bone; marginal gains may be smaller when baseline purchase is adequate. A broad circumferential cement cloud along the screw body is mechanically more efficient than a small distal bolus. More cement can increase strength, but returns diminish and leakage risk rises. PMMA offers immediate strength but is nonresorbable, exothermic, and biologically inert. Calcium-phosphate cements are osteoconductive and less exothermic but generally provide lower immediate mechanical performance and less extensive clinical evidence.

3) Augmentation techniques

Table 2: Principal PMMA augmentation methods.

Technique	Advantages	Limitations / hazards
Fenestrated cannulated screw	Screw placed before injection; cement delivered through side holes; controlled location; convenient multilevel workflow	Leakage through venous channels or breach; fenestration may reduce core strength; system-specific volume and viscosity
Pre-injection + solid screw	Works with standard screws; cement tract can be tailored; strong screw–cement interlock	Timing-sensitive; insertion can drive cement; early insertion may extrude liquid cement, late insertion increases torque and revision difficulty
Vertebroplasty then screw	Can reinforce fractured body and create a cement mantle	Distribution less predictable relative to threads; added puncture/injection step
Rescue augmentation	Useful for stripped tract or revision after poor purchase	Breach must be excluded; removal of a well-cemented screw can damage pedicle/vertebra

Fenestrated screws are increasingly favored because injection occurs after final screw position is confirmed. A 2024 meta-analysis comparing fenestrated with conventional screws plus cement suggested better fixation-related outcomes for fenestrated designs, but the underlying studies were mostly small and nonrandomized. The side holes should remain within the vertebral body, away from the posterior wall; a pedicle breach converts a manageable leak risk into a neural hazard.

4) Indications and selective use

Reasonable indications include severe osteoporosis with planned instrumented fusion; poor intraoperative purchase despite appropriate trajectory and screw size; osteoporotic fracture requiring posterior fixation; long adult-deformity constructs with critical anchor demands; sacral fixation at risk of loosening; tumor-related bone loss; and revision with an enlarged tract. Cementation need not involve every screw. Strategic augmentation of proximal/distal anchors, sacral screws, the vertebra adjacent to a fracture, or levels with the lowest HU can reduce cement burden.

Relative contraindications include uncorrected coagulopathy or infection, cement allergy, major pedicle or posterior-wall breach, substantial intravertebral venous channels, and situations in which cement cannot be monitored safely. Cardiopulmonary disease does not absolutely prohibit augmentation, but lowers tolerance for embolic load and strengthens the case for limited levels and volume.

5) Technical principles

- **Trajectory.** Maximize cortical contact with an accurate, preferably longer and larger-diameter screw when anatomy permits. Cement does not compensate for malposition.
- **Breach check.** Confirm an intact tract and final screw position before injection; consider navigation, triggered EMG, fluoroscopy, or intraoperative CT according to context.
- **Cement state.** Inject radiopaque high-viscosity cement after it reaches a doughy phase appropriate for the delivery system. Low-viscosity, high-pressure injection increases venous escape.
- **Volume.** Use the minimum volume that produces a useful peri-screw cloud. Common practice is roughly 1–2 mL thoracic and 2–3 mL lumbar per screw, but anatomy, cement, and manufacturer labeling govern.
- **Imaging.** Use continuous lateral fluoroscopy with intermittent AP confirmation. Stop immediately for posterior, epidural, foraminal, discal, or rapid venous migration.
- **Construct.** Avoid creating isolated hyper-rigid anchors without considering rod contour, interbody support, pelvic fixation, transition rods/hooks/tethers, and the upper instrumented vertebra.

6) Clinical effectiveness

The most consistent clinical signal is reduced loosening. The 2023 Song meta-analysis included 12 comparative studies and 881 patients with osteoporotic thoracolumbar degenerative disease. Cement augmentation reduced loosening (OR 0.13, 95% CI 0.07–0.22), increased fusion (OR 2.80, 95% CI 1.49–5.25), and increased intervertebral height; operating time was about 15 minutes longer, while blood loss and hospital stay were similar. Most studies were retrospective and from a limited geographic base.

A 2026 meta-analysis focused on osteoporotic lumbar spondylolisthesis reported lower loosening (OR 0.18), higher fusion (OR 3.98), and small improvements in pain and disability, with approximately 32 minutes additional operating time and no detected overall complication difference. These results strengthen the fixation signal but do not establish universal augmentation, because selection bias, technique heterogeneity, and inconsistent imaging for leakage remain.

7) Complications

Table 3: Major complications and mitigation

Complication	Clinical relevance	Risk reduction / response
Cement leakage	Often asymptomatic; epidural/foraminal leak can injure neural elements	High viscosity, low pressure, live imaging, intact pedicle; stop injection immediately
Pulmonary cement embolism	Frequently radiographic; rare hypoxia, pulmonary hypertension, right-heart strain, death	Limit screws/volume, avoid rapid venous filling; investigate symptoms; multidisciplinary management
Thermal/chemical injury	Potential neural or tissue injury from polymerization and monomer	Avoid canal leak and excessive bolus; allow appropriate viscosity
Mechanical stress transfer	Very rigid anchors may shift failure to junction, rod, adjacent vertebra, or screw core	Treat construct globally; avoid indiscriminate cementation
Revision difficulty	Cemented screw removal may fracture pedicle/body or leave a large defect	Plan extraction; consider controlled back-out, high-speed burr, alternative anchors
Infection	PMMA is an avascular foreign material; deep infection can require complex removal	Standard prevention; avoid cement in active infection

The 2021 complication meta-analysis pooled 20 studies: any cement leakage occurred in 21.8%, symptomatic leakage in 1.2%, PCE in 3.0%, symptomatic PCE in 0.8%, screw loosening in 2.0%, breakage in 0.6%, and migration in 0.2%. These estimates depend heavily on surveillance; routine CT identifies far more small leaks than plain radiographs. In a study using postoperative chest CT, radiological PCE was 16.3% and symptomatic PCE 1.4%; constructs longer than seven levels, more than 14 fenestrated screws, and total cement above approximately 20–25 mL were associated with symptomatic events.

Postoperative chest CT is not universally required in asymptomatic patients. New hypoxia, chest pain, tachycardia, unexplained hypotension, or right-heart strain after augmentation warrants prompt assessment. Treatment of PCE depends on symptoms, location, cardiopulmonary effect, and whether cement is central or peripheral; evidence is case-based, so pulmonary/critical-care and vascular/cardiothoracic input may be needed.

8) Cement is not the whole strategy

Cement provides immediate local strength but does not improve bone biology, fusion substrate, or future fracture risk. Correct vitamin D and calcium deficiency, address secondary causes, stop smoking, optimize nutrition and fall risk, and initiate osteoporosis pharmacotherapy. The CNS guideline gives a Grade B recommendation to consider preoperative teriparatide in osteoporotic patients undergoing instrumentation; 2025 AO Spine recommendations similarly favor anabolic therapy in high-risk adult deformity patients when feasible. Timing should be individualized with an osteoporosis specialist.

Construct-level adjuncts include cortical bone trajectory where appropriate, larger/longer screws, undertapping, expandable screws, hooks or sublaminar fixation, multi-rod support, robust pelvic fixation, interbody cages with broad endplate contact, vertebral augmentation at selected junctional levels, ligament/tether augmentation, and avoidance of overcorrection. None has a universal indication; the strategy should match the failure mode.

9) Practical algorithm

Table 4: A selective, failure-mode-based approach

Step	Decision	Action
1. Screen	Fragility fracture, age/risk factors, low DEXA or HU?	Obtain complete bone-health assessment and start optimization
2. Map failure risk	Short vs long construct; fracture, deformity, pelvis, junctions; HU by level	Identify anchors where failure would be catastrophic
3. Optimize construct	Can trajectory, screw size, interbody support, pelvic fixation, or alignment reduce demand?	Use mechanical solutions before adding cement indiscriminately
4. Select augmentation	Severe osteoporosis or inadequate critical-level purchase?	Prefer targeted augmentation; define maximum screws and cement load
5. Inject safely	Intact pedicle, correct screw/fenestration position, suitable cement viscosity?	Low-pressure live-fluoroscopic injection; stop at any hazardous migration
6. Follow	Symptoms, radiographic loosening, junctional change, fusion, new fracture	Continue bone medication and surveillance; investigate cardiopulmonary symptoms promptly

10) Evidence gaps and future directions

High-quality randomized trials are scarce. Needed studies include HU- or torque-based thresholds for augmentation; selective versus all-screw cementation; standardized cement volume and viscosity; comparative trials of fenestrated, solid, expandable, and cortical-trajectory screws; routine CT-defined leakage outcomes; long-term junctional and adjacent-fracture effects; and cost-effectiveness. Navigation-integrated injection monitoring, pressure-sensing delivery, lower-exotherm bioactive cements, and patient-specific finite-element planning are promising but not yet established standards.

2. Conclusions

Cement-augmented pedicle screws have a well-supported biomechanical role and a consistent clinical association with lower loosening in osteoporotic thoracolumbar fixation. Their value is greatest when baseline purchase is poor and anchor failure would compromise the construct. Fenestrated systems offer practical, controlled delivery but do not eliminate leakage. Cement should be injected selectively, at low pressure, in a high-viscosity state, under continuous imaging, using the minimum effective volume. Radiographic leakage is common; symptomatic neural injury and PCE are uncommon but potentially severe. Cement augmentation should be embedded within bone-health optimization and a construct-wide plan rather than used as a universal solution.

3. Clinical Take-Home Points

- Treat osteoporosis and the construct—not only the screw tract.
- Select augmentation by failure risk, HU/BMD, and actual purchase; avoid routine all-screw cementation.
- Fenestrated screws simplify post-placement delivery; side holes must remain safely within the body.
- A broad peri-screw cement cloud matters more than maximal cement volume.
- Stop immediately for venous, posterior, foraminal, epidural, or discal migration.
- Expect radiographic leakage to exceed symptomatic complications; maintain vigilance for PCE.
- Plan the exit strategy: revision of a cemented anchor can be destructive.

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