Bone

Efficacy of an FDA Approved Synthetic Nano-Bioactive Glass Plus Demineralized Bone Matrix (DBM) Combination versus DBM Alone in Instrumented Lumbar Fusion for Low-Grade Degenerative Spondylolisthesis: A Prospective Randomized Controlled Trial Pilot Study

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Abstract:	Background Demineralized Bone Matrix (DBM) is widely used in spinal fusion but has donor variability and supply limitations. Synthetic bioactive glass (BAG) offers osteoinductive and osteoconductive properties. NanoFuse™ DBM, an FDA-approved combination of nano-BAG and DBM, integrates bioactive nanomaterials with organic bone matrix, but its efficacy in spinal fusion remains underexplored. This study evaluates its impact on fusion success and clinical outcomes compared to DBM alone. Methods In a randomized controlled trial, 64 patients underwent single-level lumbar fusion and were followed for 36 months. Group 1 (n=29) received nano-BAG+DBM with an interspinous fixation device, while Group 2 (n=35) received DBM alone with pedicle screws and posterior lumbar interbody fusion. Both groups received an equivalent graft volume. Outcomes included radiographic fusion, Visual Analog Scale (VAS), Oswestry Disability Index (ODI), surgical parameters, and revisions. Results Both groups achieved 100% fusion at 24 months, but Group 1 demonstrated earlier fusion at 6 and 12 months. Group 1 had significantly lower VAS scores at 24 ($P = 0.041$) and 36 months ($P < 0.001$). ODI improved in both groups, with greater recovery in Group 1 ($P < 0.00001$). Group 1 also had shorter operative times and reduced blood loss. Two patients (5.71%) in Group 2 required revision for adjacent segment disease. Conclusion

	Nano-BAG+DBM accelerated early bone fusion and improved clinical outcomes while reducing DBM requirements and reliance on cadaveric bone. These findings highlight its role as a synthetic alternative for spinal fusion and its potential in bone regenerative strategies.
Opposed Reviewers:	

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Structured Abstract

Background: Demineralized Bone Matrix (DBM) is widely used in spinal fusion but has donor variability and supply limitations. Synthetic bioactive glass (BAG) offers osteoinductive and osteoconductive properties. NanoFuse™ DBM, an FDA-approved combination of nano-BAG and DBM, integrates bioactive nanomaterials with organic bone matrix, but its efficacy in spinal fusion remains underexplored. This study evaluates its impact on fusion success and clinical outcomes compared to DBM alone.

Methods: In a randomized controlled trial, 64 patients underwent single-level lumbar fusion and were followed for 36 months. Group 1 (n=29) received nano-BAG+DBM with an interspinous fixation device, while Group 2 (n=35) received DBM alone with pedicle screws and posterior lumbar interbody fusion. Both groups received an equivalent graft volume. Outcomes included radiographic fusion, Visual Analog Scale (VAS), Oswestry Disability Index (ODI), surgical parameters, and revisions.

Results: Both groups achieved 100% fusion at 24 months, but Group 1 demonstrated earlier fusion at 6 and 12 months. Group 1 had significantly lower VAS scores at 24 ($P = 0.041$) and 36 months ($P < 0.001$). ODI improved in both groups, with greater recovery in Group 1 ($P < 0.00001$). Group 1 also had shorter operative times and reduced blood loss. Two patients (5.71%) in Group 2 required revision for adjacent segment disease.

Conclusion: Nano-BAG+DBM accelerated early bone fusion and improved clinical outcomes while reducing DBM requirements and reliance on cadaveric bone. These findings highlight its role as a synthetic alternative for spinal fusion and its potential in bone regenerative strategies.

Keywords: Lumbar fusion, Demineralized Bone Matrix (DBM), Bioactive Glass (BAG), NanoFuse™ DBM, Interspinous fixation, Bone Graft Alternative, Lamellar Bone.

1. Introduction

Degenerative disc disease (DDD) and spondylolisthesis are prevalent spinal conditions that frequently lead to chronic pain, disability, and progressive neurological deficits. DDD results from the degeneration of intervertebral discs, leading to reduced disc height, diminished shock absorption, and potential nerve compression [1-4]. Spondylolisthesis, defined by the anterior displacement of one vertebra over another, further compromises spinal stability and may cause nerve root impingement [5]. Although conservative treatments such as physical therapy, pain management, activity modification, and epidural steroid injections [6-9] are typically first-line management, surgical intervention becomes necessary when these measures fail or when instability worsens [10].

Interbody cages combined with pedicle screw instrumentation have long been considered the benchmark for posterior stabilization in the treatment of degenerative spondylolisthesis, offering robust biomechanical support and high fusion rates [11, 12]. Despite the proven effectiveness of pedicle screw fixation since its introduction in the 1940s, [13, 14] pedicle screw fixation (PSF) has been associated with drawbacks, including prolonged operative times, increased blood loss, screw malposition, and the development of adjacent segment disease (ASD). Consequently, non-pedicular fixation alternatives such as interspinous fixation devices (IFDs) have emerged, as they stabilize the spine by fixating the spinous processes and lamina posteriorly, thereby eliminating the need for pedicle screws [15]. These devices have been associated with shorter operative times, reduced blood loss, and decreased intraoperative complications [16, 17] and potentially reducing adjacent segment disease [18].

With approximately 1.3 million lumbar fusion procedures billed to Medicare Part B in the United States between 2000 and 2019, and annual lumbar interbody fusions nearly doubling from about

61,000 to roughly 119,000, these statistics underscore the growing demand for spinal fusion among an aging population [19]. The success of lumbar fusion procedures is highly dependent on the selection of an appropriate bone graft material, which is critical for achieving robust osseointegration and long-term spinal stability [20].

Historically, autologous iliac crest bone graft (ICBG) has been considered the gold standard for spinal fusion owing to its osteogenic, osteoinductive, and osteoconductive properties [21-23]. However, the use of ICBG is limited by donor site morbidity, including pain, cluneal nerve injury, infection risk, and structural compromise of the iliac crest, which has prompted the exploration of alternative graft materials [24, 25]. As a result, demineralized bone matrix (DBM), derived from processed allograft bone and retaining essential osteoinductive proteins such as bone morphogenetic proteins (BMPs), has become widely adopted [26-28]. Although DBM provides an osteoconductive properties, its clinical efficacy can be inconsistent due to donor variability and a lack of mechanical support [29].

To address these limitations, synthetic bone substitutes like bioactive glass (BAG) have been introduced to enhance osteogenesis and improve structural integrity [30]. In particular, the 45S5 composition of BAG, developed by Professor Larry Hench in 1969, has demonstrated significant osteostimulative properties [31] by releasing biologically active calcium, phosphate, and silicon ions that stimulate osteoblastic differentiation and promote bone matrix mineralization. BAG is composed of inorganic metallic oxides and exhibit inherent osteoconductive properties that foster bone regeneration and healing. Their dense, nonporous structure provides superior durability and strength compared to other ceramic materials [32]. In addition, BAG exhibits antimicrobial properties that may reduce the risk of postoperative infections. Animal studies,

such as those by Pajamaki et al. [33-35], indicate that BAG can accelerate bone induction when combined with DBM.

Despite these theoretical advantages, the efficacy of nano-BAG+DBM in lumbar fusion remains largely unexplored. Given the unique biomechanical and anatomical characteristics of the lumbar spine, further investigation is warranted to determine whether BAG and DBM combination can yield clinical and radiographic outcomes comparable to those achieved with DBM alone. The objective of this study aims to be the first to evaluate the safety and efficacy of nano-bioactive glass combined with demineralized bone matrix (nano-BAG+DBM) versus DBM alone in single-level instrumented lumbar fusion for grade 1 degenerative spondylolisthesis. We aim to determine whether nano-BAG+DBM promotes earlier fusion at 12 months compared to DBM alone in lumbar fusions.

2. Materials and Methods

2.1. Nano-Bioactive Glass and Demineralized Bone Matrix Combination

NanoFuse™ DBM (NanoFuse Biologics LLC, Burlington, MA) represents the only U.S. Food and Drug Administration (FDA) approved osteobiologic that combines 45S5 BAG with DBM, integrating the osteoinductive benefits of DBM with the osteostimulatory and antimicrobial advantages of BAG. The product by weight is 33% DBM cortical bone, 33% 45S5 Bioglass and 33% porcine gelatin. This composite graft offers a promising alternative to autografts by potentially enhancing fusion rates while reducing surgical morbidity.

2.2. Study Design

This prospective, randomized controlled trial (RCT) enrolled patients between 2019 and 2022 to evaluate the efficacy and safety of nano-BAG+DBM versus DBM alone in single-level

instrumented lumbar fusion. The study included individuals diagnosed with low-grade degenerative spondylolisthesis who had not responded to conservative treatment for a minimum of six months. This study was granted Institutional Review Board (IRB) approval through Western Institutional Review Board (WIRB®) now known as WIRB-Copernicus Group (WCG® IRB) (WIRB#20181251) and informed consent was obtained from all individual participants.

2.3. Participants and Eligibility Criteria

A total of 64 patients meeting the inclusive criteria for instrumented fusion groups were enrolled. All surgeries were performed by a single board-certified orthopedic spine surgeon in an outpatient setting. Inclusion criteria included adults aged 18 to 75 years with symptomatic grade 1 degenerative spondylolisthesis at a single lumbar level (L2-S1) who failed nonoperative treatment for at least six months and were able to comply with postoperative follow-up (Figure 1). Exclusion criteria included acute trauma, fractures, malignancy, active infection, prior lumbar fusion or total disc replacement, severe osteoporosis or metabolic bone disease, chronic uncontrolled systemic illness (e.g., diabetes, autoimmune disorders), and a body mass index (BMI) >42.

2.4. Randomization and Allocation

Block randomization was employed to ensure balanced allocation of patients between treatment groups. Eligible patients were randomly assigned to either Group 1 (nano-BAG+DBM+IFD, n=29) and received fusion with IFD and 10 cc of nano-BAG+DBM (n=29) or Group 2 (DBM+PSF) and underwent fusion with PLIF and PSF and 10 cc of DBM Pure (n=35) using a structured block system. The randomization process was managed by the surgical coordinator, ensuring unbiased assignment. The treating surgeon was not aware of the randomization process

or treatment allocation. No patients refused treatment, and no crossovers occurred between groups.

2.5. Blinding

Radiologists assessing pre and postoperative radiographic images were blinded to group allocation to ensure objective imaging analysis. However, due to the distinct surgical techniques used in each group, blinding of participants and care providers was not feasible.

2.6. Surgical Technique

All patients underwent a midline posterior lumbar decompression followed by instrumented fusion. For Group 1, the interlaminar space was prepared, and InSpan IFD (InSpan LLC, Burlington, MA, USA) was measured and fixated to the spinous processes and lamina [16, 17]. NanoFuse™ DBM (Nano-BAG+DBM) was mixed with autograft and applied over the decorticated facet joints and within the interlaminar space to facilitate fusion (Figure 2). For Group 2, the intervertebral disc space was prepared for standard PLIF procedure and two PLIF cages packed with DBM (DBM Pure, LESSpine Inc., Burlington, MA, USA) mixed with autograft were inserted. Bilateral pedicle screws and rods were placed for posterior stabilization, and DBM was applied over the decorticated facet joints.

2.7. Follow-Up

Patients were monitored postoperatively and discharged based on standard outpatient surgical criteria. Follow-up visits were conducted at 3 months, 6 months, 12 months, 24 months and 36 months. Clinical and radiographic evaluations were conducted to assess fusion progress, pain levels, and functional outcomes.

2.8. Outcomes

The primary outcome of this study was radiographic fusion, assessed using dynamic X-rays (flexion-extension lateral views) and CT scans at 6, 12, 24, and 36 months. Facet fusion was graded using the following classification: Grade I (complete bone continuity across the facet joint), Grade II (continuous but incomplete bone formation), Grade III (uncertain bony continuity), and Grade IV (obvious nonunion) [36, 37]. Fusion was considered successful if either one or both facet joints achieved Grade I or II fusion. Interbody fusion was defined according to Lebwohl et al., where the presence of continuous bone bridging in the interspace anterior to the cage on lateral radiographs was considered definitive fusion [38]. Secondary outcomes included patient-reported outcome measures (PROMs), perioperative parameters, and long-term surgical outcomes. PROMs were assessed using the Visual Analog Scale (VAS) and the Oswestry Disability Index (ODI) at baseline and at 6, 12, 24, and 36 months to evaluate pain relief and functional improvement. Perioperative parameters included operative time, estimated blood loss (EBL), and intraoperative complications. Long-term surgical outcomes included implant-related failures, revision rates, and the development of adjacent segment disease (ASD).

2.9. Sample Size and Power Analysis

The sample size was based on expected differences in fusion rates at 6 months, the primary outcome. We hypothesized that Group 1 would achieve earlier fusion compared to Group 2. A priori power analysis was conducted to determine the necessary sample size to detect a moderate to large effect size with statistical confidence. To achieve 80% power at a 0.05 significance level, a minimum of 32 patients per group (64 total) was required. This sample size balanced statistical power with study feasibility. Despite unequal group sizes, 29 and 35, the total sample size remained sufficient to detect meaningful differences. A post-hoc power analysis confirmed that the sample size remained adequate to detect a clinically relevant effect.

2.10. Statistical Analysis

All statistical analyses were performed using Python-based tools (pandas, scipy.stats, statsmodels) within Visual Studio Code. Continuous variables (VAS, ODI, operative time, and EBL) were analyzed using independent samples t-tests for between-group comparisons and paired t-tests for within-group changes. Effect sizes were quantified using Cohen's d. Normality was assessed using the Shapiro-Wilk test, and Levene's test evaluated homogeneity of variances. When normality or variance assumptions were violated, non-parametric comparisons were performing using the Mann-Whitney U test for between-group analyses and the Wilcoxon test for within-group paired data. Categorical variables, including fusion status, revision rates, and complication rates, were analyzed using the Chi-square test with Yates' continuity correction or Fisher's exact test when expected frequencies were <5. For multiple comparisons with unequal variances, the Games-Howell test was applied to adjust for standard errors. Statistical significance was set at $P < 0.05$.

3. Results

A total of 64 patients were enrolled and randomized into two groups. Group 1 (n = 29, 62.1% female) received nano-BAG+DBM+IFD, while Group 2 (n = 35, 51.43% female) received DBM+PSF. All participants completed their assigned treatments and follow-up visits, with no dropouts. Baseline characteristics, including age ($P = 0.513$) and BMI ($P = 0.648$), were comparable between groups.

Radiographic Fusion Outcomes

Radiographic evaluations confirmed 100% fusion at 24 months in both groups (Figures 3 and 4). However, fusion patterns differed between groups. Group 1 demonstrated earlier interspinous

fusion and unilateral Grade II facet fusion by 6 months, with definitive Grade I facet fusion by 12 months. In contrast, Group 2 showed early interbody fusion within the cage at 12 months, reaching definitive fusion and Grade II facet fusion at 24 months.

Pain and Functional Outcomes

Both groups demonstrated significant postoperative improvements in pain and function. In Group 1, VAS scores decreased from 8.08 ± 1.62 preoperatively to 4.05 ± 3.14 at 12 months ($P < 0.001$). Between 12 and 24 months, VAS remained stable (4.04 ± 2.62), but further improved at 36 months (3.04 ± 2.31, $P = 0.02$). In Group 2, VAS scores declined from 8.17 ± 0.95 to 5.5 ± 0.66 at 12 months ($P < 0.001$), but remained comparable at 24 months (5.54 ± 0.95, $P = 0.301$) and 36 months (5.08 ± 0.65, $P = 0.458$). Between-group comparisons revealed no significant difference in VAS at 12 months ($P = 0.162$), but Group 1 had significantly lower pain scores at 24 months ($P = 0.041$) and 36 months ($P < 0.001$), compared to Group 2 with a moderate and large effect size of 0.76 and 1.15.

Functional outcomes also improved significantly in both groups. Group 1 showed a greater reduction in ODI from 51.45% ± 7.76 preoperatively to 16.30% ± 8.96 at 24 months, compared to Group 2, which decreased from 51.57% ± 6.19 to 33.34% ± 3.85. Group 1 exhibited significantly greater functional improvement ($P < 0.00001$).

Operative and Surgical Outcomes

Group 1 demonstrated shorter operative times (94 ± 13 minutes vs. 146 ± 21 minutes; $P < 0.001$) and lower EBL (72.90 ± 44.65 mL vs. 297.43 ± 80.31 mL; $P < 0.00001$). No intraoperative complications occurred in either group. Although no revisions were required in Group 1, two patients (5.71%) in Group 2 required revision surgery for adjacent segment disease; however,

this difference was not statistically significant (Fisher's exact test, P = 1.0). No implant-related failures were reported in either group.

4. Discussion

4.1. Brief Summary and Purpose of This Study

This study assessed the safety and efficacy of nano-BAG+DBM combination in single-level instrumented lumbar fusion compared to DBM alone for patients with low-grade spondylolisthesis. BAG is recognized for its ability to enhance osteogenic activity, stimulate angiogenesis, exert antimicrobial properties due to its ionic release and contribute to high fusion rates in cervical and lumbar spine surgery [31, 39-41]

4.2. Summary of Key Findings

Our results demonstrated that both groups achieved 100% radiographic fusion at 24 months, confirming that the addition of BAG to DBM does not compromise fusion success. Notably, Group 1 (nano-BAG+DBM+IFD) exhibited earlier facet fusion, with Grade II fusion evident at 6 months and definite Grade I fusion by 12 months, compared to the Group 2 (DBM+PSR), which showed definitive fusion at 24 months. This accelerated fusion in Group 1 may be attributed to BAG's dual function as both a scaffold and a source of biologically active ions that enhance the osteogenic potential of DBM. In contrast, Group 2's use of interbody cages likely delayed interbody fusion, while pedicle screws and rods may have contributed to stress shielding of the facets and interbody space, slowing the overall fusion process. The less rigid fixation provided by the IFD in Group 1 appeared to promote bone remodeling in accordance with Wolff's Law [42], resulting in earlier and more pronounced radiographic fusion.

An *in vivo* animal model demonstrated that instrumentation improved fusion rates for posterolateral spine fusion; however, more rigid instrumentation led to the formation of histologically woven bone [43], which is less mineralized and appears more radiolucent. According to Wolff's law, Group 1, where mechanical stress is maintained at the facets, is expected to form lamellar bone, whose highly organized and mineralized structure creates clear, dense (radiopaque) images on radiographs, making it superior for visualizing facet fusion compared to the stress-shielded woven bone seen in Group 2.

No complications were reported in either group; however, Group 1 benefited from significantly reduced operative times and lower blood loss, likely due to the reduced instrumentation and the absence of interbody cages. The achievement of 100% facet fusion highlighted the effectiveness of the nano-BAG+DBM combination independent of pedicle screw and cage use. While no implant failures occurred in either group, it is noteworthy that, despite the known strength of pedicle screws coupled with interbody cages for three-column fixation [44, 45], the earlier facet and interspinous fusion observed in Group 2 may have helped protect the less rigid fixation construct from developing ASD by reducing stress on adjacent segments. In contrast, two patients in the Group 2 developed ASD that required revision surgery.

4.3. Comparison with Existing Literature

Our findings align with previous studies that highlight the osteoinductive and osteoconductive properties of BAG, supporting its role as an effective bone graft substitute that promotes bone healing and structural integrity. For instance, animal studies by Pajamaki et al. [33-35] demonstrated that BAG implants can accelerate bone induction when combined with DBM, which may explain the earlier facet fusion observed in our nano-BAG+DBM group compared to DBM alone. Moreover, a meta-analysis by Cottrill et al. [46]. confirmed that BAG enhances

spinal fusion rates via its osteostimulatory effects, offering a viable alternative to both DBM and autografts without increasing the risk of deep wound infections. A 4-year randomized controlled trial reported that BAG spacers achieved fusion rates and clinical outcomes comparable to those of autologous bone grafts and titanium cages in single-level PLIF [47], while another randomized trial found no significant difference in fusion success between BAG spacers (89.7%) and titanium cages (91.2%) at 12 months post-surgery [48]. Szadkowski et al. reported that in anterior lumbar interbody fusion (ALIF) procedures performed at L5-S1 or L4-L5, fusion rates achieved using BAG were equivalent to those obtained with autologous ICBG [49]. This finding indicates that BAG can effectively replace autologous grafts, thereby reducing operative time, blood loss, and the complications associated with donor site morbidity.

In the context of instrumented lumbar fusion, high fusion rates have been achieved using PSR constructs combined with interbody cages; however, these techniques are often associated with complications such as ASD [50]. Consequently, IFDs have been explored as alternatives, as they provide adequate stabilization with the added benefits of shorter operative times, reduced blood loss, and decreased tissue disruption, potentially mitigating the risk of ASD. Stand-alone interspinous lumbar instrumented fusion with bone grafting has also shown promising results in promoting fusion in patients with unstable grade 1 degenerative spondylolisthesis with comparable outcomes to PLIF [51]. When IFD is used in conjunction with anterior or lateral lumbar interbody fusion (ALIF/LLIF), significant improvements in early postoperative patient-reported outcomes (≤12 months) were observed with robust posterior fusion and minimal complications [15].

4.4. Clinical Implications

Our study indicates that integrating BAG with DBM offers a promising alternative to using DBM alone in lumbar fusion, particularly in outpatient settings where less invasive techniques are favored. BAG provides a standardized, reproducible graft option that mitigates the donor variability issues often seen with DBM, when used in equivalent volumes. Furthermore, as a synthetic inorganic material, bioactive glass circumvents the need for harvesting cadaveric or autologous bone, ensuring a reliable and cost-effective supply [32].

4.5. Limitations

This study's single-center design and relatively small sample size (n=64) may affect the generalizability of our findings. Although the follow-up period extended to 36 months, it may not fully capture long-term outcomes such as implant subsidence, adjacent segment degeneration, or late-stage nonunion. Additionally, two different fixation methods were used: Group 1 employed an IFD, which provides less rigid stabilization compared to the pedicle screws and interbody cages used in Group 2. This methodological difference, particularly in light of the earlier facet fusion observed in Group 1, could potentially confound the results. Future multi-center studies with larger cohorts and extended follow-up periods are needed to validate fusion rates, assess efficacy against other synthetic grafts and autograft alternatives with similar instrumentation, and evaluate performance in multi-level fusion procedures, ultimately clarifying the clinical utility of nano-BAG+DBM in spinal fusion.

5. Conclusion

Posterior instrumentation using both nano-bioactive glass and DBM combination and DBM alone achieved 100% radiographic fusion. Notably, the nano-BAG+DBM group with interspinous fixation devices demonstrated earlier facet fusion compared to the DBM group

utilizing a pedicle screw-rod construct. These findings support the use of nano-BAG+DBM as a viable alternative for instrumented lumbar fusion procedures that do not require pedicle screws or interbody cages in selected patients. Moreover, using an equivalent volume of the nano-BAG+DBM composite compared to DBM alone suggests that BAG's enhanced osteogenic capabilities can lower the total DBM needed, thereby reducing reliance on cadaveric bone. The osteoconductive and osteostimulatory properties of BAG further augment the bone-forming potential of DBM [33-35], offering a reproducible, synthetic alternative to human-derived grafts.

CRediT authorship contribution statement:

William M. Costigan MD – Conceptualization, Supervision. Erik Spayde MD – Conceptualization, Supervision. Vito Lore PE – Supervision. Hope Estevez – Project administration. Sukanya Chebrolu MS - Writing – original draft, Project administration. Chukwunonso C. Ilogu MD - Data curation, Writing – original draft, Formal analysis. Jason A. Seale MBBS - Writing – review and editing, Visualization. Kingsley R. Chin MD - Conceptualization, Methodology, Supervision.

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Data availability:

Data will be made available on request.

Figure Legend:

Figure 1: Female patient with L3-4 grade 1 degenerative spondylolisthesis and ligamentum flavum hypertrophy, Modic endplate changes, disc desiccation and spinal stenosis on MRI.

Figure 2: NanoFuseTM DBM inserted following decompression and fusion with InSpan interspinous fixation device

Figure 3: Postoperative Computed Tomography (CT) Scan at 24 months showing (A) Grade I facet fusion and (B and C) Interspinous Fusion.

Figure 4: L5-S1 decompression and instrumented fusion with bilateral PLIF cages and pedicle screws-rod construct. Postoperative Computed Tomography (CT) Scan at 24 months showed interbody fusion and grade II facet fusion.

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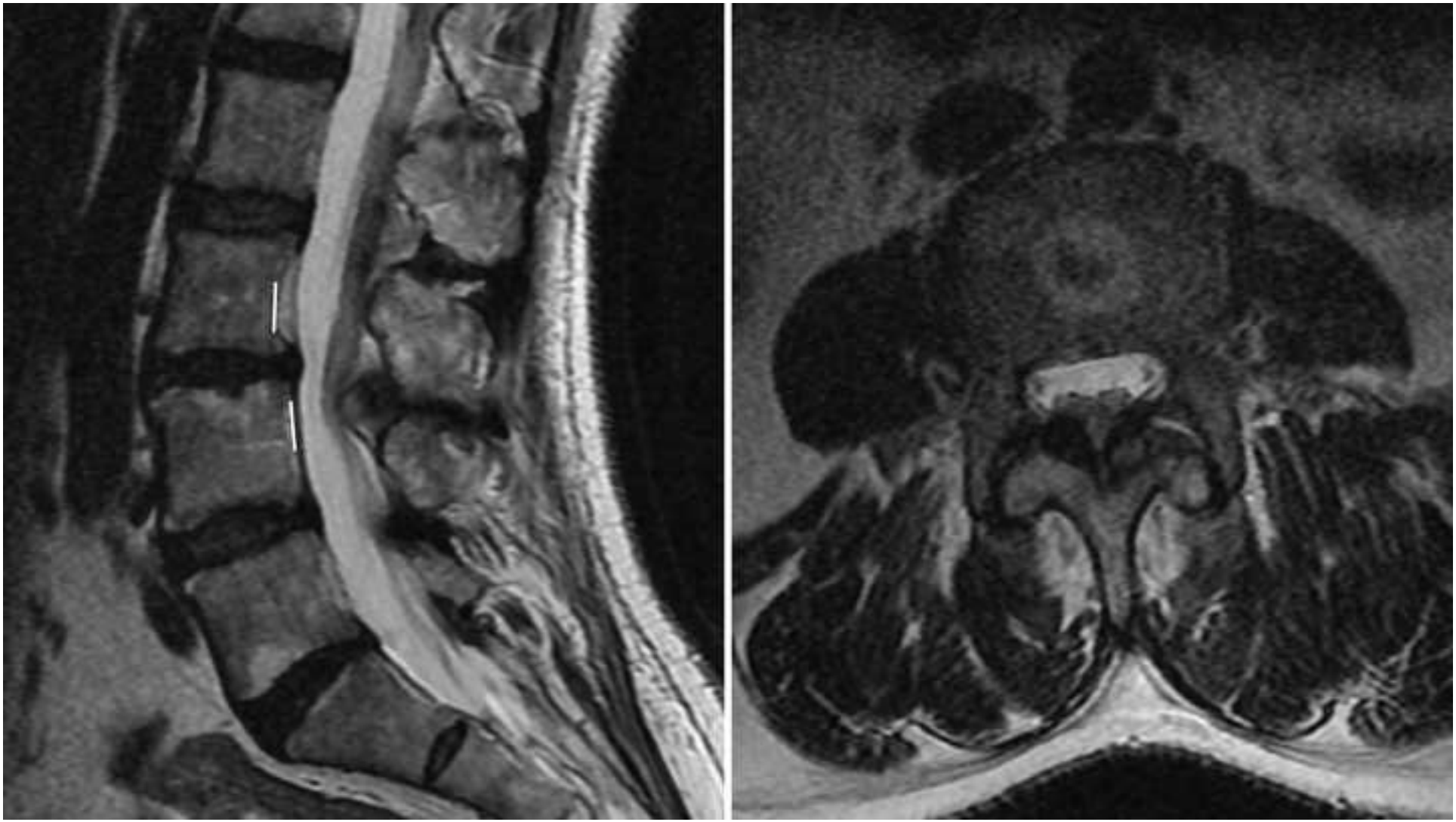
Figure(s)



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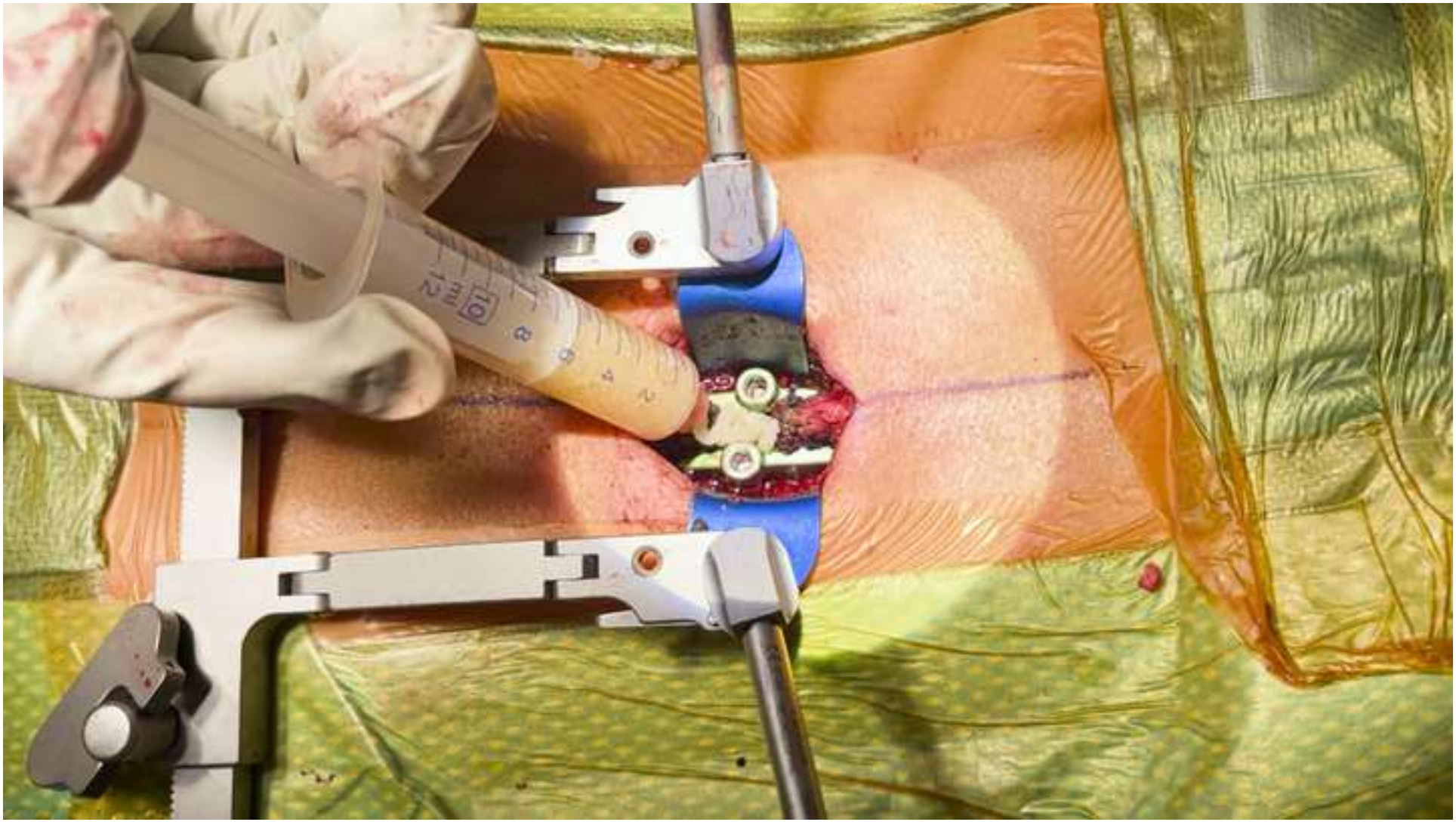

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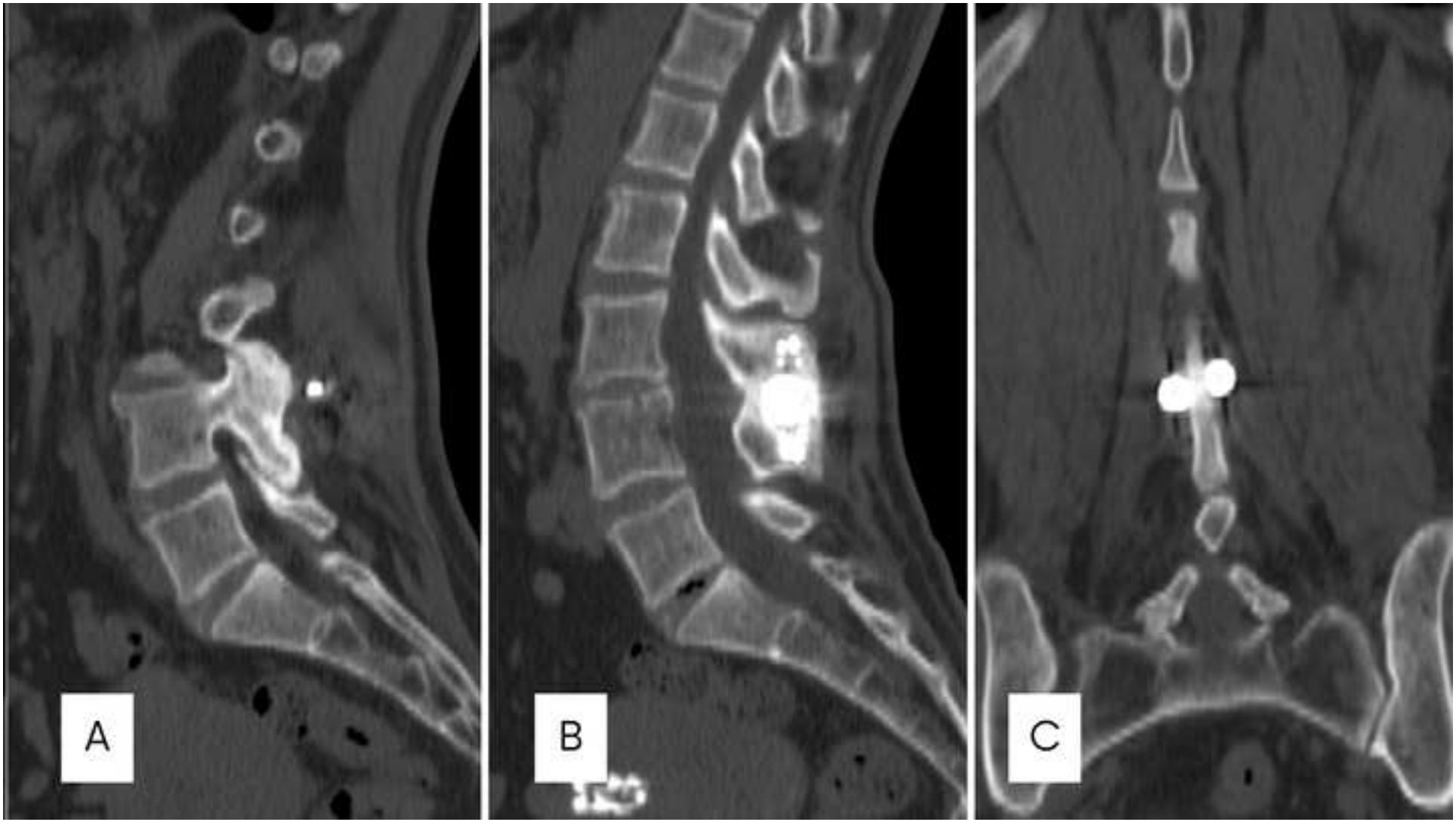

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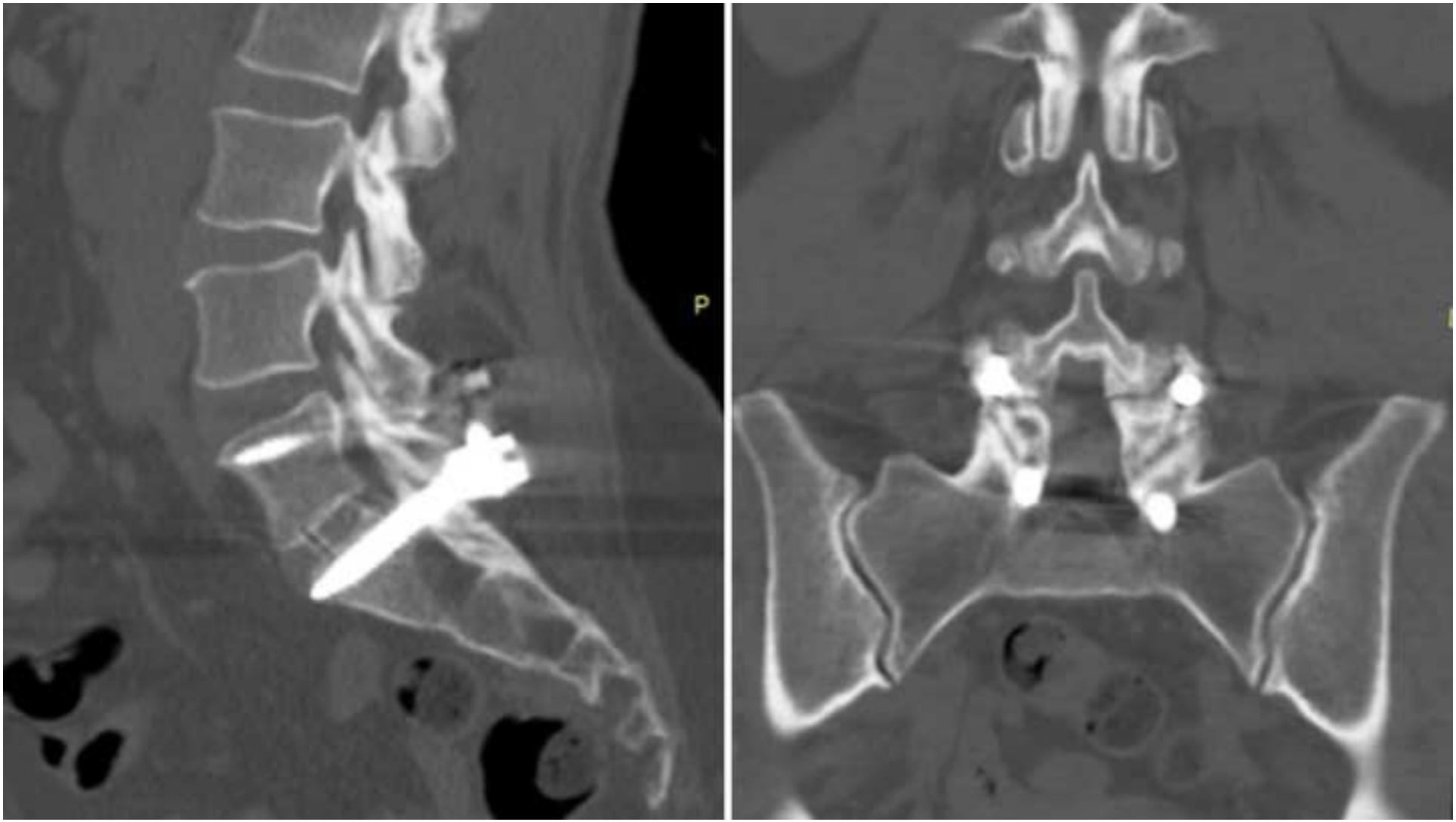

Highlights

1. Nano-BAG+DBM fused earlier at 6 months compared to DBM alone at 12 months.
2. Fusion rates were similar using equal volumes of nano-BAG+DBM and DBM.
3. Nano-BAG+DBM lowered VAS pain scores and improved ODI functional outcomes.
4. BAG's osteogenic properties may reduce DBM needs and reliance on cadaveric bone.
5. Nano-BAG+DBM is a synthetic alternative for spinal fusion biomaterials.