

Prediction of Screw Loosening Possibility According to Bone Cement Insertion During Multi-Level Fusion in Osteoporosis Patients: A Finite Element Analysis

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INTRODUCTION: Surgical methods for patients with degenerative lumbar spinal stenosis encompass laminectomy-based decompression surgery and fusion surgery with implant insertion. Due to common complications like excessive spinal motion and the risk of stenosis recurrence due to segmental instability post-decompression, there is a growing preference for fusion surgery with internal fixation (1). Fusion surgery is a surgical technique utilizing pedicle screws and lumbar inter-body fusion (LIF) cages to restrict unnecessary joint motion. In cases of severe lumbar stenosis resulting from factors like osteoporosis or spondylolisthesis, multi-level fusion is performed. However, implant-related complications, such as screw pull-out and vertebral fracture, are frequently observed during long-segment fusion. These complications are particularly common in the upper instrumented vertebrae (UIV), leading to correction loss and nonunion. Although cement-augmented screws are utilized to prevent implant failure, studies investigating the effect of cement augmentation of UIV in multi-level lumbar inter-body fusions are still limited (2). Thus, this study employed finite element analysis to predict the improvement effect of screw loosening with Cement augmentation during multi-level fusion and compared the outcomes under osteoporosis (OP) conditions.

METHODS: In this study, a three-dimensional normal spine finite element model was verified through previous studies was used (3). OLIF Cage (E: 3.5GPa, ν : 0.3; GS Medical Corp.) for L2-S1 levels and PLIF Cage (E: 3.5GPa, ν : 0.3; GS Medical Corp.) for L5-S1 level were used for inter-body fusions. Pedicle screws (E: 110GPa, ν : 0.3; GS Medical Corp.) were used for the fixation of the spinal column. In the cement augmentation model, pedicle screws with bone cement (E: 3.5GPa, ν : 0.3) were inserted into the UIV (L2), which is the most commonly reported site of fixation failure in multi-level fusion. The bone cement was constructed in a lump shape with a volume of 2.5 cm³, following the same clinical procedures (4). The annulus and ligament of the segment (L2-S1) were partially removed, and the nucleus was completely removed for the insertion of inter-body cages. A total of four surgical models were implemented based on the presence of Cement augmentation and the application of osteoporosis for the Pedicle screw inserted at L2 (Type A: No Cement; Type B: L2 Cement augmentation; Type A-OP, Type B-OP) (Fig 1). Each bone was assigned the properties of Grade 5 osteoporosis, which represents the most severe condition (5), and compared with the normal model (Table 1). A 'Tied contact' was applied, assuming complete fusion between the implant and bone, and the lower part of S1 was fully constrained against all movements. In order to implement the muscle force as a load condition, a follower load of 400N and a pure moment of 10Nm were applied to the upper endplate of L1 to perform six spinal motions (flexion, extension, left lateral bending, right lateral bending, left axial rotation, right axial rotation) was reproduced (6). The degree of screw loosening was assessed by deriving the peak von Mises stress (PVMS) generated at the interface between L2 and pedicle screw of each type compared to the yield stress of the vertebral body (16MPa, Type A) and cement (92 MPa, Type B) (7,8). In addition, the possibility of degeneration of adjacent segments was evaluated by analyzing the motion of adjacent segments (L1-L2) based on normal spinal motion.

RESULTS: As a result, at the interface between the insertion site and the pedicle screw, the stress values for Cement augmentation (Type B: 17.43 MPa, 18.91%; Type B-OP: 24.42 MPa, 26.49%) were found to be lower than those for conventional multi-level fusion (Type A: 6.41 MPa, 39.32%; Type A-OP: 14.67 MPa, 90%). Particularly in the model with osteoporosis, the stress values decreased by approximately 70%. The motion of adjacent segments showed similar results in both groups compared to normal spine (Type A: 98%, Type B: 98%), suggesting that cement augmentation does not affect the degeneration of adjacent segments (Fig 2). This indicates that the injection of bone cement effectively reduces stress at the pedicle screw insertion site, lowering the risk of screw loosening, with even more significant benefits for osteoporosis patients.

DISCUSSION: Based on the results of the study, the possibility of screw loosening can be reduced without affecting the motion of adjacent segments, when cement augmentation is performed in UIV. Although further trials are needed to validate our results in clinical situations, cement-augmented screws in UIV can be considered in multi-level lumbar inter-body fusions to prevent implant failure.

SIGNIFICANCE: Cement augmentation in upper instrumented vertebrae during multi-level lumbar inter-body fusion surgeries reduces stress, lowering implant failure risk, especially in osteoporosis cases, without affecting adjacent segment motion. This technique offers promise for enhancing fusion stability in complex spinal surgeries.

REFERENCES: [1] Yuan L. et al., 2021, [2] Tang, Y.C., et al., 2020, [3] Chen, W.M., et al., 2009, [4] Zhou, Q.K., et al., 2020, [5] Kurutz et al., 2012, [6] Philips, F.M., et al., 2009, [7] Hur, J.W., et al., 2021, [8] Sun, H.L., et al., 2017

Grade of age-related degeneration (Young's modulus [MPa] / Poisson's ratio)	Intact	Grade 5
Nucleus pulposus	1.0 / 0.499	81 / 0.3
Annulus ground substance	4.2 / 0.45	6 / 0.45
Cancellous bone	150 / 0.3	50 / 0.3
Endplate	100 / 0.4	20 / 0.4

Table 1. Material properties for osteoporosis

