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Basic Research

Assessing spatio-temporal, kinematic and kinetic gait parameters in patients with degenerative cervical spinal stenosis

F. Mandelli[1,2], R. Cottier[2], C. Nüesch[2,3,4], A. Mündermann[2,3,4,5], S. Schären[2,3,4], C. Netzer[2,3,4]
[1]Department of Spine Surgery, Hospital Zollikerberg, Zollikerberg, Switzerland; [2]Department of Spine Surgery, University Hospital Basel, Basel, Switzerland; [3]Department of Biomedical Engineering, University of Basel, Basel, Switzerland; [4]Department of Clinical Research, University of Basel, Basel, Switzerland; [5]Department of Teaching, Research and Development, Schulthess Clinic Zurich, Zurich, Switzerland

Objective: The aims of this study were i) to compare gait parameters between patients with cervical spinal stenosis (CSS) with or without radiological signs of myelopathy and healthy controls and ii) to explore the correlation between gait and patient-reported outcome measures (PROMs) in the CSS population.
Methods: Patients with CSS were included and divided into two groups according to the presence (group CSS-M) or absence (CSS-nM) of cervical intramedullary hyperintensity on T2-weighted MRI images. A separate cohort of healthy individuals served as controls. Spatiotemporal, kinematic and kinetic gait parameters were assessed during level walking at comfortable, self-selected speed using a 3D motion capture system and the PlugIn-Gait model (Vicon, Oxford, UK). Comparison between groups was performed using Kruskal-Wallis test with post-hoc Dunn's tests ($P<0.05$). PROMs (Neck disability index (NDI) modified Japanese Orthopaedic Association Score (mJOA)) were collected only from patients. The correlation of gait parameters with PROMs in patients was assessed using Spearman's Rho.
Results: Overall, 15 patients in the sCSS-M group (age, mean (standard deviation): 60.7 (12.9) years; NDI score median [interquartile range], 10 [1,18]); mJOA, 16 [15,17]), 23 patients in the sCSS-nM group (age, 62.1 (9,7) years; NDI score, 11 [5, 19]; mJOA, 16 [16, 17]), and 30 healthy controls (age, 63.8 (7.5) years) were included. There were no differences between the groups in spatiotemporal, kinematic and kinetic parameters (Table 1). Patients with a higher (i.e., worse) NDI score exhibited shorter stride lengths (rho=-0.384). Higher NDI and lower mJOA scores correlated with a lower maximum external ankle dorsiflexion moment (rho=-0.441 and rho=0.343 respectively), and a smaller dorsiflexion moment impulse (rho=-0.362 and rho=0.338 respectively).
Conclusion: Our results suggest that patients with greater subjective functional impairment, as measured by PROMs, also exhibit more limitations in ankle joint function during push-off from the ground. Contrary to previous literature [1], our findings do not reveal differences in spatiotemporal, kinematic or kinetic gait parameters between patients with or without intramedullary hyperintensity on MRI images. These results highlight the critical role of clinical assessment in the diagnostic management of cervical myelopathy.

	Median [IQR]			Kruskal-Wallis
	Controls	CSS-nM	CSS-M	3 groups
speed (m/s)	1.31 [1.21,1.44]	1.28 [1.11,1.41]	1.21 [1.02,1.45]	0.305
cadence (steps/min)	110.54 [105.55,116.13]	109.75 [101.48,118.95]	109.21 [103.13,117.01]	0.927
stride length (m)	1.39 [1.33,1.60]	1.38 [1.28,1.43]	1.33 [1.23,1.50]	0.385
stride time (s)	1.08 [1.03,1.14]	1.09 [1.01,1.18]	1.11 [1.03,1.17]	0.923
stance (%gc)	61.51 [59.90,62.02]	61.53 [60.94,62.74]	62.23 [59.97,63.56]	0.285
min ankle angle loading response (°)	-1.1 [-2.8,1.5]	-0.3 [-2.2,1.7]	-0.2 [-3.4,3.3]	0.785
max ankle angle stance (°)	15.9 [12.8,18.6]	16.3 [13.1,19.0]	16.0 [14.4,18.5]	0.997
min ankle angle push-off (°)	-13.1 [-17.71,-8.3]	-10.5 [-16.2,-8.4]	-8.2 [-11.2,-7.1]	0.054
min ankle moment (Nm/kg)	-0.21 [-0.28,-0.16]	-0.19 [-0.27,-0.10]	-0.19 [-0.28,-0.13]	0.470
max ankle moment (Nm/kg)	1.42 [1.24,1.60]	1.42 [1.26,1.58]	1.44 [1.29,1.59]	0.937
ankle dorsiflexion moment impulse (Nm/kg * s)	2007.6 [1645.3,2411.3]	2166.7 [1886.0,2289.3]	2151.1 [1955.2,2389.8]	0.681
max ankle power (W/kg)	3.46 [2.97-4.25]	3.69 [2.87,4.41]	3.10 [2.15,4.02]	0.164

Promoting Intervertebral Disc Fusion: Synergistic Osteogenic Induction of Human Annulus Fibrosus Cells Using BMP2, L51P, and the EP4 Agonist KMN159

S. Häckel[1,2], S. Chen[3,4], T. Xinggui[5,6], S. Zwingenberger[5,6], C. E. Albers[1], B. Gantenbein[1,3]
[1]Department of Orthopaedic Surgery and Traumatology, Inselspital, Bern University Hospital, Bern, Switzerland; [2]Graduate School of Health Science, University of Bern, Bern, Switzerland; [3]Department for Bio-Medical Research (DBMR), Tissue Engineering for Orthopedics & Mechanobiology (TOM), Bone & Joint Program, University of Bern, Bern, Switzerland; [4]Graduate School for Cellular and Biomedical Sciences, University of Bern, Bern, Switzerland; [5]University Center of Orthopedic, Trauma and Plastic Surgery, University Hospital Carl Gustav Carus at TU Dresden, Dresden, Germany; [6]Center for Translational Bone, Joint and Soft Tissue Research, University Hospital Carl Gustav Carus at TU Dresden, Dresden, Germany

Objective: Spontaneous fusion is a known feature of advanced disc degeneration, often characterized by osteophyte formation and segmental auto-fusion. Building on this biological potential, we investigated the feasibility of inducing intervertebral disc fusion in vitro using a combination of pro-osteogenic factors. This study assessed the osteogenic differentiation of human annulus fibrosus (AF) cells treated with bone morphogenetic protein 2 (BMP2), its inhibitor-resistant analog L51P, and the selective prostaglandin E2 receptor EP4 agonist KMN159.
Methods: Primary human AFCs ($n = 11$) were cultured for 21 days with BMP2, L51P, and KMN159, alone and in combination. Cell viability was assessed to exclude cytotoxicity. Osteogenic differentiation was evaluated via gene expression of alkaline phosphatase (ALP), osterix (SP7), and type I collagen (COL1), as well as mRNA expression of BMP antagonists (Noggin, Gremlin 1, Chordin). ALP activity was quantified on day 14, and alizarin red staining was performed on day 21 to assess calcium deposition.
Results: KMN159 alone had no cytotoxic effects and exhibited weaker osteogenic activity than BMP2. However, the combination of BMP2, L51P, and KMN159 significantly enhanced osteogenesis: ALP gene expression increased 25-fold, and ALP protein activity was elevated 5.43-fold relative to BMP2 alone (day 14). Upregulation of BMP antagonists was observed, particularly Noggin ($p < 0.05$). On day 21, the BMP2 + L51P + KMN159 group showed the highest calcium deposition (mean 17.91 mM), representing a 1.33-fold increase in relative mineralization over BMP2 alone. Statistical analysis revealed a significant effect of treatment group ($F(6, 41.32) = 6.92$, $p < 0.001$) and age ($F(1, 6.87) = 8.53$, $p = 0.023$), with older donors demonstrating higher osteogenic activity.
Conclusion: These results suggest that BMP2, L51P, and KMN159 act synergistically to enhance osteogenic differentiation in AFCs, particularly in aged or degenerative disc environments. This biologically based strategy may inform future approaches to promote intervertebral disc fusion.

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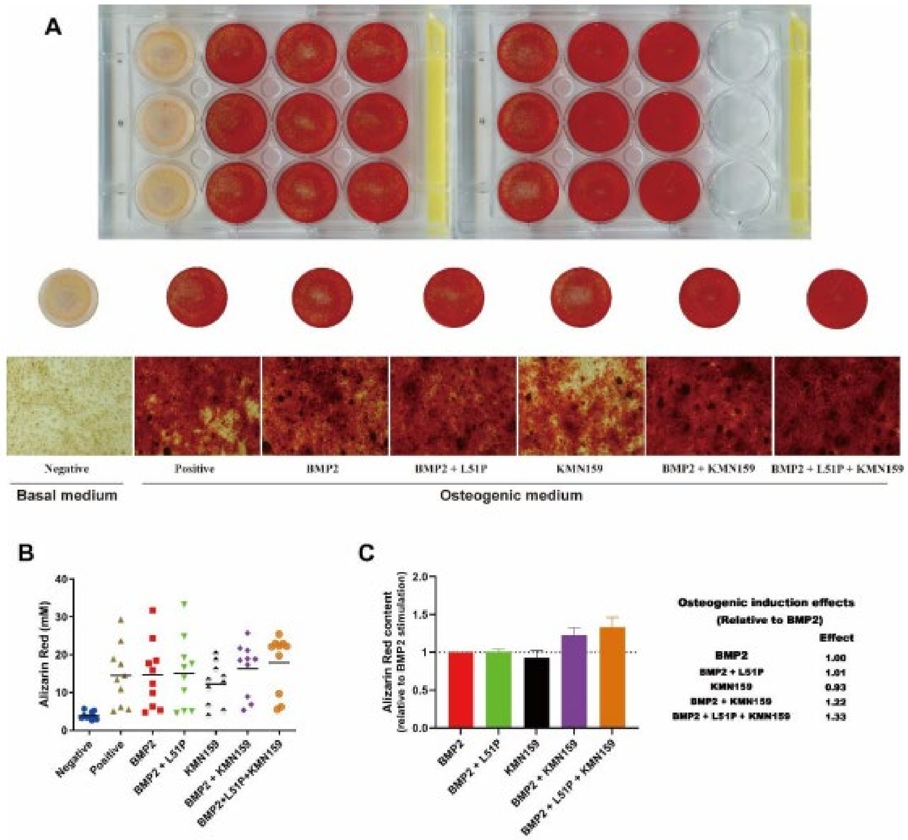

Figure 1: Alizarin red staining and quantification of calcium deposition in AFCs after 21 days of osteogenic induction. (**A**) Representative staining images showing that the BMP2 + L51P + KMN159 group exhibited the most intense mineralization. (**B**) Quantification of alizarin red content (mM) in different groups. (**C**) Relative mineralization levels normalized to the BMP2 group, and the BMP2 + L51P + KMN159 group showing the highest calcium deposition, reaching a 1.33-fold increase. Data are shown as mean (mean ± SEM for **C**); *n* = 10.

Biomechanics of Spinal Fusion Under Simulated Fully Flexed Position: Load Analysis Using Sensor-Equipped Rods and Cages

M. Khodaee[1, 2], A. Tsolakidis[3], T. Götschi[1], T. Jang[2], M. Farshad[3], J. Widmer[1]
[1]Spine Biomechanics, Department of Orthopedic Surgery, Balgrist University Hospital, Zurich, Switzerland; [2]Department of Information Technology and Electrical Engineering, ETH Zurich, Zurich, Switzerland; [3]Department of Orthopedics, University of Zurich, Balgrist University Hospital, Zurich, Switzerland

Objective: Spinal fusion surgery is commonly used to stabilize the spine and relieve symptoms. In full flexion, inactive paraspinal muscles shift load to osseoligamentous structures and instrumentation, increasing the risk of screw loosening, pseudoarthrosis, or implant failure. Understanding construct biomechanics in this posture is clinically important. We examined loads on fixation rods and intervertebral cages during full flexion with an intact disc, PLIF, or TLIF cage, before and after decompression, cage subsidence, or removal.
Methods: Twelve single-level lumbar segments from fresh-frozen cadavers were dissected with preserved discs and bony structures. A custom setup simulated full flexion by converting a 100 N axial load into an 18.6 N·m sagittal bending moment via the spinous process and endplate. Specimens were instrumented with two strain-gauged fixation rods and four pedicle screws (N = 4), or additionally with a PLIF (N = 4) or TLIF (N = 4) cage, each containing two force sensors.

In no-cage specimens, decompression steps (laminotomy, nucleotomy, facetectomy) were performed, and rod loads measured. In cage groups, rod and cage loads were recorded before and after simulated cage subsidence and removal. Rod load was quantified by correlating strain data with applied moments after removing all other components.
Results: In full flexion, fixation rods experienced extension bending in all groups. At 18.6 N·m, median rod bending load was 2.7% lower in the PLIF group and 13.7% higher in the TLIF group compared to the no-cage group. Median normalized cage loads were 17.1 N/N·m (TLIF) and 15.8 N/N·m (PLIF). After endplate disruption and cage removal, median rod load dropped by 41.3% and 44.0% ($p = .009$ and .003). Cage load fell from 16.0 to 8.0 N/N·m ($p = .001$).
Progressive decompression increased median rod load by 4.9–6.9% after uni- or bilateral laminotomy, midline decompression, and partial nucleotomy ($p = .090$ to $< .001$). Complete nucleotomy reduced the median by 41.2% ($p = .004$). Further steps, including partial, complete, and bilateral facetectomy raised load by less than 1.8%.
Conclusion: In full flexion under high bending moments, fixation rods experience extension bending, potentially a critical load for posterior fusion structures. After endplate disruption or complete nucleotomy, load shifts from rods and cages to anatomical structures.

The effect of decompression techniques on lumbar spinous process strength

K. Hatziisaak[1], F. Cornaz[1], J. Widmer[1], M. Farshad[2]
[1]Spine Biomechanics, Universitätsklinik Balgrist, Zurich, Switzerland; [2]Universitäres Wirbelsäulenzentrum, Universitätsklinik Balgrist, Zurich, Switzerland

Objective: Lumbar decompression procedures can have varying effects on the biomechanics of the lumbar spine. The spinous processes are of increasing interest for dynamic stabilization techniques such as Vertebropexy and their load-bearing capacity may be affected by different decompression techniques to varying degrees. This study aims to quantify the effect of decompression techniques on the strength of the lumbar spinous processes and hypothesizes that the extent of osseous decompression influences the load-bearing capacity of the spinous processes.
Methods: Twenty-four fresh-frozen human cadaver lumbar spine specimens (L1/2: 12, L3/4: 12) were divided into four groups: native control (n=6), unilateral over the top laminotomy (n=6), bilateral laminotomy (n=6), and midline laminotomy (n=6). A 10 mm wide polyester band was wrapped around the spinous processes and a biomechanical testing setup was employed to apply increasing flexion torques until failure. The ultimate torques □Nm□ were measured and the four groups were compared using ANOVA. To control for confounding factors, bone mineral density in the vertebral bodies (BMD-VB) and the spinous processes (BMD-SP) as well as the spinous process area (SPA) in the frontal plane were compared between the groups.
Results: The mean (standard deviation) ultimate torque was 46.3 Nm (22.1 Nm) for native, 57.1 Nm (19.7 Nm) for unilateral laminotomy, 44.7 Nm (10.9 Nm) for bilateral laminotomy and 44.9 Nm (16.34 Nm) for partial midline laminotomy. Statistical analysis showed no significant difference ($p = 0.6$) between the four assessed groups. The groups were comparable regarding BMD-VB ($p = 0.8$), BMD-SP ($p = 0.2$) and SPA ($p = 0.6$).
Conclusion: These findings suggest that, within the limits of this study, the assessed decompression methods do not significantly compromise spinous process strength. Consequently, all examined techniques may represent biomechanically viable options for decompression preceding interspinous stabilization procedures. While the study focused on surgical factors, further research is warranted to explore how other variables affect spinous process strength.

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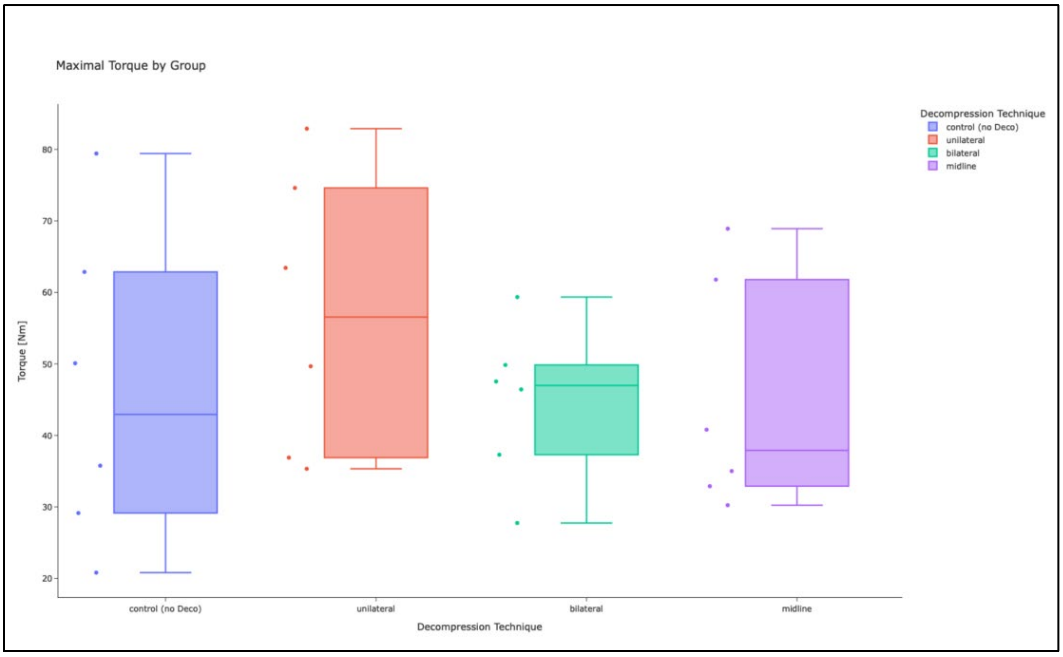


The "Rescue Screw" as a freehand revision strategy for implant loosening – A comparative biomechanical study on human cadavers

M. Farshad[1], A. Alakmeh[1], R. Rohner[2], M. Suter[2], F. Wanivenhaus[1], J. Widmer[2], C. Laux[1]
[1]University Spine Center Zurich, Balgrist University Hospital, Zurich, Switzerland; [2]Spine Biomechanics, Balgrist Campus, Zurich, Switzerland

Objective: Depending on bone mineral density, implant loosening occurs in up to 54 % of cases after spinal instrumentation. This leads to compromised healing, instability and mechanical pain, often requiring surgical revision. Revision strategies strongly depend on the remaining bone stock within the pedicle and include the use of larger diameter or dual pitch screws, implant cementation, alternative screw trajectories such as the cortical bone trajectory (CBT), impaction grafting, and extension to the intact adjacent segment. This study biomechanically compares screws with a 2 mm larger diameter (LD), CBT screws, and craniocaudal "rescue screws" (RS) in the setting of loosened cemented and native index pedicle screws.

Methods: The vertebral bodies of 5 human cadaveric lumbar spines were dissected. After randomization and simulated screw loosening with a 1 mm larger tapping, each test trajectory was tested in alternating order on all lumbar levels. RS and LD screws were analyzed for cemented and uncemented index pedicle screws. The respective contralateral pedicle was instrumented with a conventional pedicle screw as an intra-sample reference. Maximum bending load-to-failure [Nm] in flexion/extension was recorded for all screws in a biomechanic testing machine.

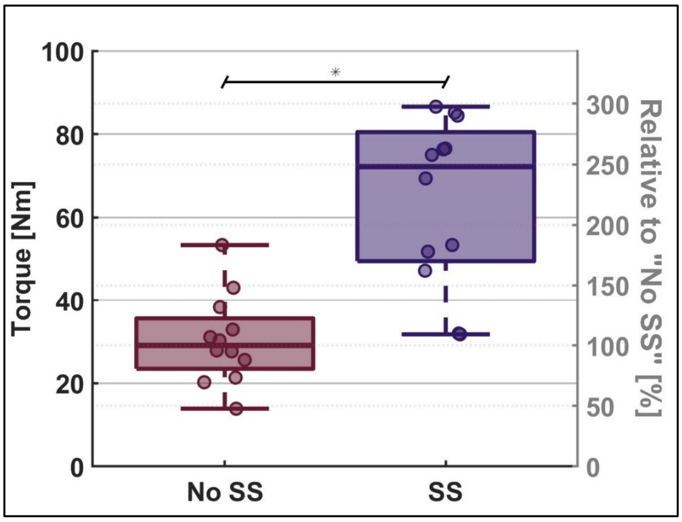
Results: In total, revision screws showed a significantly higher (+25.9 %; p=0.006) maximum torque (34 Nm) than controls (27 Nm). In native index screws, LD screws showed the highest median torque (35.3 Nm; +19.5 %). RS screws showed an 11.6 % torque increase (32.1 Nm) compared to contralateral controls. In cemented index screws, this effect was even greater for both LD (45.1 Nm, +59.2 %) and RS screws (48.9 Nm; +41%). CBT screws did not restore the mechanical strength of the index screw in the context of prior screw loosening (29.4 Nm; -2.7 %).

Conclusion: LD screws showed the best mechanical performance in this cadaveric screw loosening model for cemented and native index pedicle screws. The rescue pedicle screw offers a biomechanically robust and technically easy revision strategy if larger diameter screws are no longer applicable due to significant bone loss. CBT screws are biomechanically less suitable for the revision of loosened pedicle screws.

A safety sling more than doubles the mechanical stability of pedicle screws: a preventive measure against pedicle screw loosening in lumbar spinal fusion

A. Schuler[1], J. Widmer[1], O. Wigger[1], F. Cornaz[1], R. Rohner[1], M.-R. Fasser[1], M. Farshad[1]
[1]Spine Biomechanics, Department of Orthopedic Surgery, Balgrist University Hospital, Zurich, Switzerland

Objective: Pedicle screw loosening and pull-out are major complications in spinal fusion surgery. One potential solution to address this issue is a dorsally attached "safety sling", looped around the spinous processes, which prevents excessive loading of the screws during flexion. The goal of this study is to examine the biomechanical effectiveness of this safety sling on instrumentation resilience during simulated lumbar flexion in human spinal segments.
Methods: Twenty-four human lumbar segments were biomechanically tested under simulated flexion loads using a custom setup. Four groups (n=6 each) were compared: (1) pedicle screw instrumentation alone, (2) instrumentation with a dorsally attached safety sling, (3) instrumentation with midline decompression, and (4) instrumentation with midline decompression plus safety sling. All specimens underwent increasing flexion loads until failure to assess the safety sling's effect on screw construct stability.
Results: The safety sling demonstrated a significant improvement in pedicle screw stability during lumbar flexion: Median failure load increased by factor 2.06 with an intact midline (60.6 Nm with safety sling vs. 29.4 Nm without, p = 0.026) and by factor 2.60 in decompressed segments (75.7 Nm with safety sling vs. 29.1 Nm without, p = 0.026).
Conclusion: The concept of a dorsally attached safety sling is a highly effective supplementary measure for enhancing primary construct stability during spinal flexion. By reducing the load on the screw-bone interface, this approach represents a promising strategy to reduce the risk for screw loosening and thus revision rates in spinal fusion surgery.



Lateral mass screw placement using patient-specific templates vs. free-hand technique - a biomechanical cadaveric study

A. Stauffer[1], J. Schader[1,2], A. Schuler[1], M. Farshad[1], J. Widmer[1], J. Spirig[1]
[1]Department of Orthopaedics, Balgrist University Hospital, Zurich, Switzerland; [2]Institute for Biomechanics, ETH Zurich, Zurich, Switzerland

Objective: Cervical lateral mass screws (CLMS) are frequently used in posterior cervical instrumentation due to their easier handling and lower neurovascular risk compared to pedicle screws. However, screw loosening remains a concern, especially in patients with poor bone quality. While

template-guided systems have improved accuracy and pull-out strength in other regions of the spine, data for the cervical spine are limited. This study aims to evaluate the biomechanical advantages and accuracy of template-guided vs. freehand CLMS.

Methods: Ten fresh-frozen human cervical spines (C3–C7) were instrumented with CLMS using an alternating, randomized intra-vertebral approach. A total of 82 screws (41 guided, 41 freehand) were placed. Template-guided screws were inserted using preoperative CT-based planning and patient-specific drill guides. Freehand screws were placed by an experienced spine surgeon using anatomical landmarks. Pull-out strength was measured mechanically. Screw trajectory, complications, and placement accuracy were analyzed radiographically.

Results: Template-guided screws showed significantly higher median pull-out strength (~750 N) compared to freehand screws (~600 N). The median relative strength increase was ~15%. No significant correlation was found between pull-out strength and screw length or bicortical placement. Fewer complications, such as facet joint violation and lateral mass fractures, were observed in the guided group.

Conclusion: Template-guided CLMS placement provides superior mechanical stability and fewer placement-related complications compared to the freehand technique. Patient-specific guides may be particularly useful in cases with challenging anatomy or poor bone quality. Further clinical studies are needed to evaluate long-term outcomes.