Analysis of the segmental and adjacent level impacts of forcing the connection of misaligned pedicle screws and rods and subsequent unintended forces applied to the construct and spine: A Finite Element Analysis

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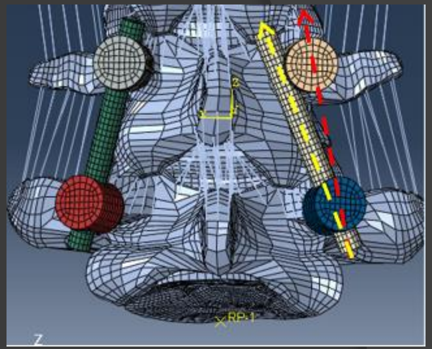
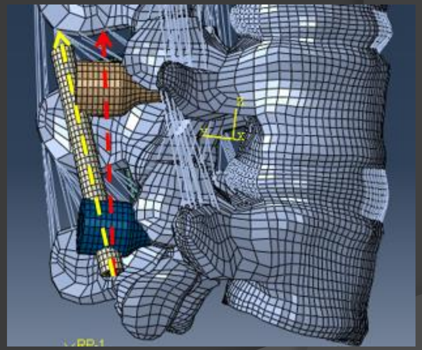
Background & Purpose

- Manual contouring of rods is often required intraoperatively for proper alignment of the rods within the pedicle screw heads. Residual malalignments are frequently reduced by using dedicated reduction devices. The forces exerted by these devices, however, are uncontrolled and may lead to excessive reactive forces.

- As a consequence, the pedicle screw-bone interface may become compromised and surrounding tissue may experience unfavorable biomechanical loads.

- The biomechanical loads on surrounding tissue and induced deformations from the reduction have not been well described previously. Additionally, it is unexplored whether the correction of the malalignment alters the biomechanical behavior of the lumbar spine during physiological movements postoperatively.





The aim of this computational study is to predict the loads and deformations in the instrumentation and surrounding tissues directly after the reduction is applied and during physiological flexion following successful fusion.

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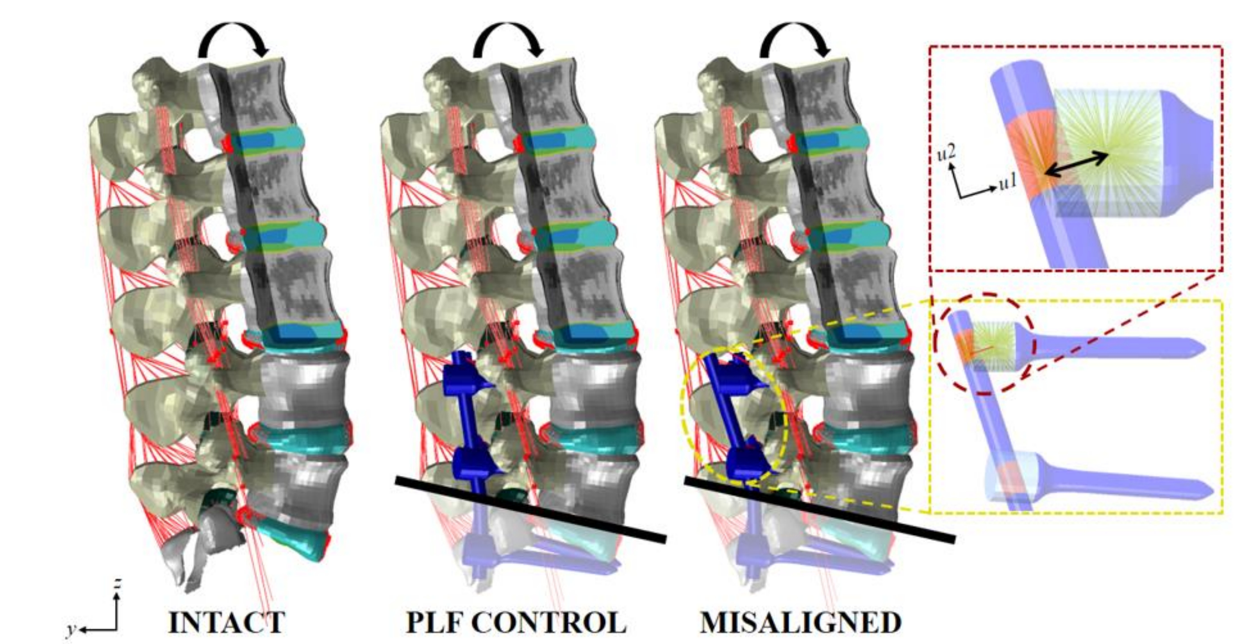
Methods

A patient-specific, total lumbar (L1-S1) spine finite element model was available from previous research [1,2]. The model consists of

- poro-elastic intervertebral discs with Pfirrmann grade dependent material parameters
- linear elastic bone tissue with stiffness values related to the local bone density
- the seven major ligaments per spinal motion segment described with a hypo-elastic stress-strain relationship.

Titanium instrumentation was implemented in this model to simulate a L4, L5, and S1 posterolateral fusion.

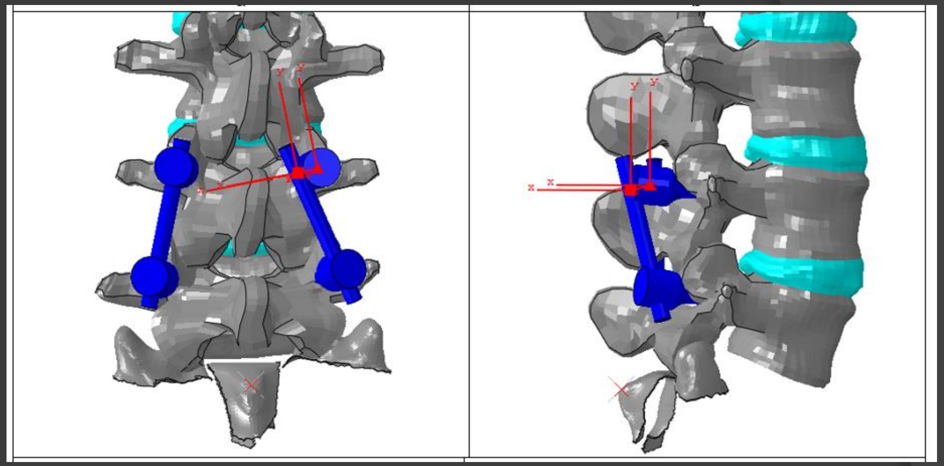


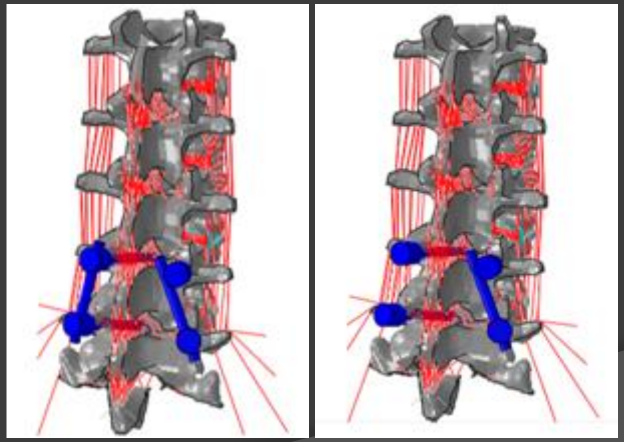
Overview of the intact control, posterolaterally fused control, and sagittally misaligned model.

References:
1. Malandrino et al, Front Bioeng Biotechnol, 3:5, 2015.
2. Rijsbergen et al, PLoS one, 13(8):e0200899, 2018

Methods

- A misalignment of six millimeters was introduced between the rod and the screw head at L4 in the coronal and sagittal plane respectively.
- These misalignments were computationally reduced after which a physiological flexion movement of fifteen degrees was prescribed.
- Two clinical situations regarding the presence of a contralateral rod were analyzed, Situation I and II.
- Non-instrumented and well-aligned instrumented models were added as control groups.





Situation I and II are visualized for the coronally misaligned rod.

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Results

- Forces of up to 1.0 kN were required to correct the induced misalignment of six millimeters.

  These results indicate, that there might be a considerable risk for screw pullout intraoperatively, during the correction, or postoperatively because of misalignment.

	Pulling force [kN]
Coronal misalignment	
Situation I	*0,9*
Situation II	*0,7*
Sagittal misalignment	
Situation I	*1,0*
Situation II	*0,7*

>300N may lead to cancellous bone failure
>628N may lead to cortical bone failure[1]

1. Wagnac E, et al. Biomechanical analysis of pedicle screw placement: a feasibility study. Research into Spinal Deformities 7. IOS Press, 2010. doi:10.3233/978-1-60750-573-0-167

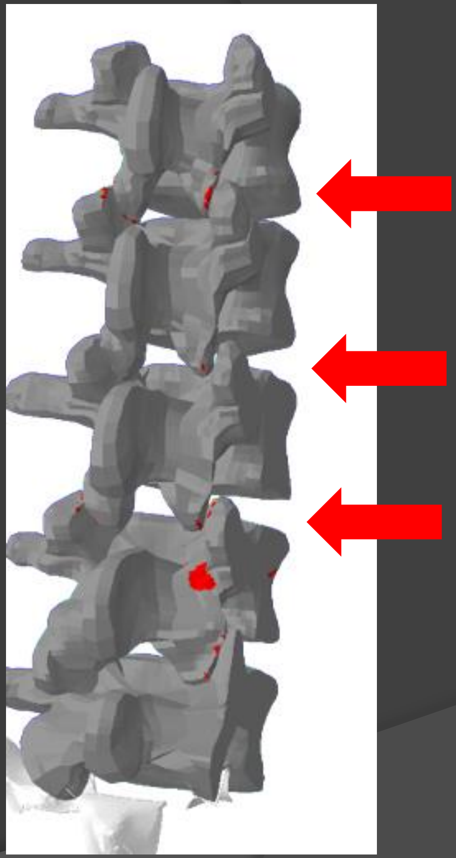
- These forces affect the posture of the total lumbar spine as motion segments were observed to rotate at adjacent segments and propagate up to and include the L1-2 segment.

Results

- Asymmetrical increased facet contact pressures of up to 6 MPa were encountered cranial to L4-5 after the correction of the misalignment.

	L1L2_l	L1L2_r	L2L3_l	L2L3_r	L3L4_l	L3L4_r	L4L5_l	L4L5_r
COR I	-	4,0	-	2,8	-	3,9	3,2	-
COR II	-	6,3	-	3,9	-	5,1	9,0	-
SAG I	-	2,0	-	2,1	-	3,3	-	-
SAG II	-	1,3	-	1,0	0,6	4,1	-	-

- The facet contact pressures in the misaligned model are substantial and asymmetrical suggesting unnatural joint loading in the misaligned models.



Bone tissue at risk

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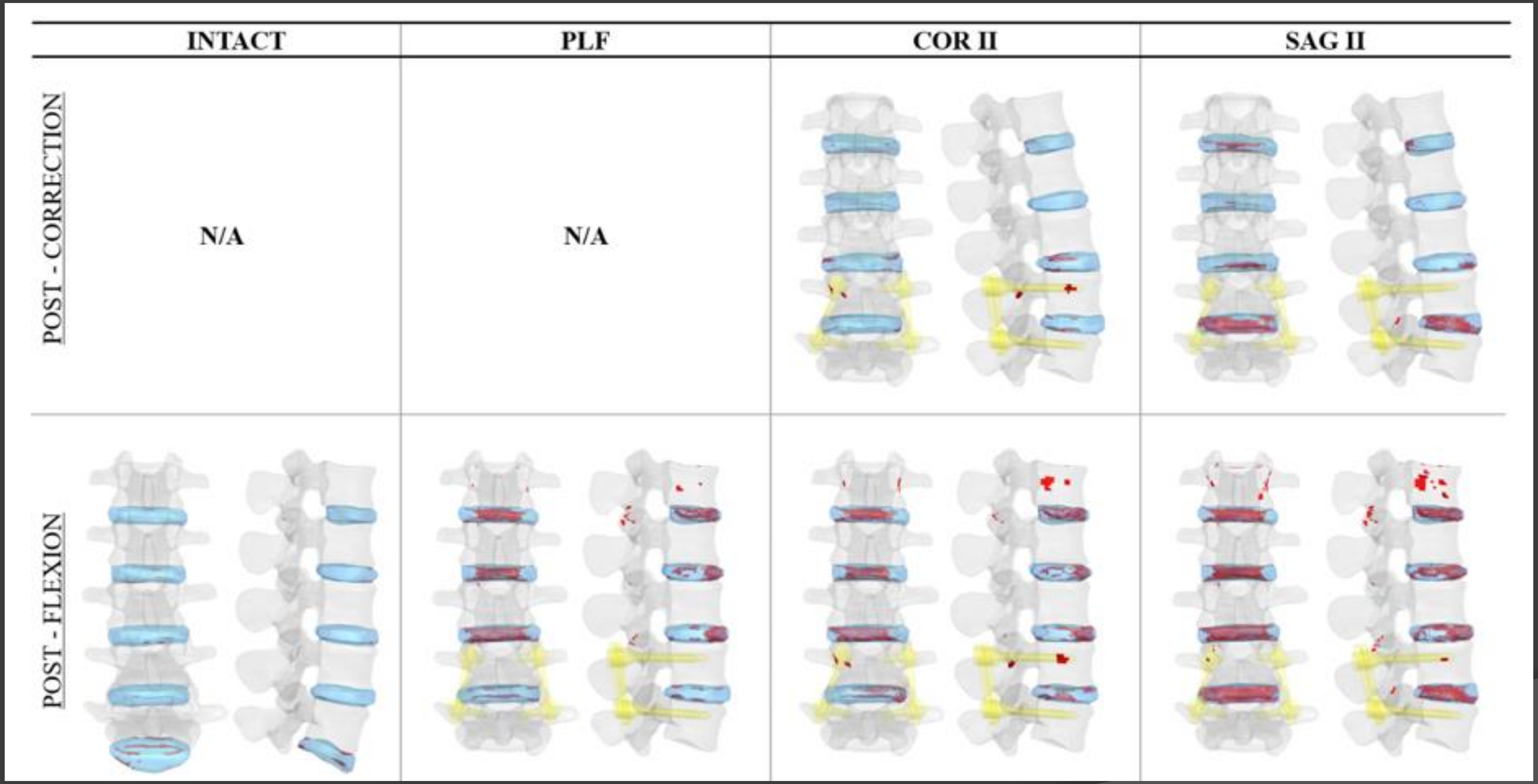
Results

- The discs and vertebrae demonstrated significant increased abnormal forces as a result of the correction procedure.



Graphical representation indicating the tissue volumes being at risk after correction and flexion (grey: vertebrae, blue: IVDs, yellow: instrumentation, red: tissue at risk).

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Conclusions

- The estimated forces required to correct a small (6mm) misalignment between a rod and screw will compromise the screw-bone interface and induce asymmetrical forces at the adjacent segments that propagate at least 3 levels proximal to the upper instrumented vertebrae.

- The tissue volume at risk (discs and vertebrae) during flexion is larger for the misaligned models in which reduction was performed.

- The deformations induced by reducing this small misalignment produce substantial unintended asymmetrical forces that demonstrate a 'domino effect' on the adjacent segments and theoretically could negatively impact patient outcome in the clinical setting.

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Thank You!