A Study of the Effects of Screw Position on Load Transfer in and around a Lumbar Pedicle Screw Using Non-idealized FEA

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Introduction: Excessive stress concentrations in bone after screw fixation in the spine can lead to localized bone failure and screw loosening, which can lead to implant failures. Similarly, increased stresses on the screw can lead to screw breakage. Angulated screw insertion during fixation has been advocated as enhancing screw fixation strength because of increased axial pullout strength, especially in bone with poor bone quality. The objective with the current study was to investigate the optimal trajectory of pedicle screw placement in the lumbar spine using non-idealized series FE-modeling. The hypothesis was that there is an ideal pedicle screw orientation for a given patient.

Methods: Surface data of seven L4 lumbar vertebrae from human spines (mean age 54.6±15.9 yrs, 3 M, 4 F, mean L4 body volume: 65.1±10.9 cm³) were extracted from CT images (ScanIP, SimpleWare, Exeter, UK) and finite element models of L4 were constructed after a meshing process (ICEM, ANSYS, Canonsburg, PA). Loads of 500 N were applied to the proximal tip of a pedicle screw inserted into the left pedicle, simulating flexion, extension, right and left axial rotation. 9 different screw trajectories were compared: a combination of 3 angles in the axial plane (lateral, straight, medial) and 3 in the sagittal plane (superior, center, inferior, Fig. 1). The maximum equivalent stresses on the cortical bone, screw and cancellous bone during the four directions of loading were studied using the seven FE- models having the same material properties but different geometries. In addition, the effects of 6 vertebral geometries (vertebral body height, width, pedicle angle, pedicle width, total length of the screw path, and vertebral volume) on maximum stresses were studied. Statistical analysis was performed using one-way RM-ANOVA and Pearson product moment correlations.

Results: The greatest relative stresses occurred in cortical bone, followed by in the screw and cancellous bone. The maximum stresses varied the most with screw angle in cortical bone, followed by in the screw and cancellous bone. The greatest stresses occurred during flexion. Ignoring sagittal plane angulation, medial screw trajectories resulted in significantly greater stresses in cancellous bone than lateral screw trajectories. Ignoring axial plane angulation, superior trajectories resulted in similar stresses in cancellous bone as inferior screw trajectories. A given size screw will produce smaller cancellous bone stresses in a larger vertebra. Superior and lateral screw placement in a vertebra with a narrow pedicle will produce greater stresses on the screw.

Conclusions: The geometry of a vertebral body, including the pedicle, has an effect on the force distribution patterns during simulated loading of a pedicle screw in the lumbar spine. The effects of different screw trajectories are influenced by vertebral geometry, with generally larger vertebrae resulting in less cancellous stress for most screw trajectories. Bone quality aside, it is possible to assess which pedicle screw orientations for a given patient should minimize stresses.
[Fig. 1. Lateral view of L4 with angled screw.]