Effect Of Varying Geometrical And Material Properties And Fixation Techniques In Posterior Lumbar Spinal Instrumentation On Spine Biomechanics: A Finite Element Study

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Introduction: Posterior spinal instrumentation spanning the entire lumbar spine for treatment of diseases like scoliotic deformation, metastatic spine disease, and unstable fractures are common. The instrumentation normally is in the form of segmental pedicle screws with connecting rods. In the surgical point of view, Low profile and low volume implants are preferable for the construct, especially in children and slender adults. The profile of the construct is determined mainly by rod diameter. Strength of 5mm rod diameter system is considered weaker than that of 6mm rod diameter system. The detail of strength of the whole construct is, however, yet to be clarified, because there are number of variables such as (i) material property of the screw-rod system, (ii) diameter of the screw and rod, (iii) pedicle screws at all the segments versus intermittent fixation and (iv) rigidity of fixation at the screw-rod junction that can influence the biomechanics of the instrumented spine. In this study, a finite element model of a lumbar spine was used to analyze the biomechanical effect of material property and size of the screw-rod system as well as segmental fixation and connectivity at the screw-rod junction of the posterior instrumentation.

Methods: A non-linear 3D poro-elastic finite element model of a lumbar spine (L1-S1) was developed from the CT scan of a normal 30 year old subject. The vertebral surface models were translated into solid models, endplates and the discs were created by connecting the superior and inferior surfaces of the adjacent vertebrae and modeled as 3D solid elements. Facet surface models were created from point-cloud data from CT scan. Seven major ligaments were modeled at each segment level. Mooney-Rivlin hyperelastic properties were assumed for the annulus. Four additional models were built to simulate two sizes of the screw-rod system (5 mm and 6 mm) and two additional models to simulate multi-level (L1 to S1) or intermittent fixation of the screws (at L1,L2,L5 and S1). Either 5mm or 6 mm screws were inserted into the pedicle using Weinstein approach \textsuperscript{(1)}. Screws and the connecting rods were modeled with young’s modulus equivalent to either TNTZ or Ti or CoCr. In one of the models (with Ti screw), elastic modulus of the connecting rods were adjusted to 300 MPa to allow for the motion at the screw-connecting rod joint in the real scenario \textsuperscript{(2)}. Inferior face of the S1 vertebra was constrained in translation in all the three principal directions. Moments of 8 Nm in flexion; 6 Nm of extension; ± 4 Nm of torsion and ± 6 Nm of lateral bending were applied to the lumbar spine independently.

Results: The intact finite element model was validated by comparing the range of motion (ROM) results against the cadaver study results. Posterior instrumentation considerably reduced the flexibility of the lumbar spine as anticipated. The ratio between motion of posterior instrumented lumbar spine and the motion in a normal spine (SR) found to vary between 150 and 480 under the three moment loading conditions. The decrease in SR due to intermittent segmental fixation varied from 1% to 13% under the three loading modes. Stiffness increase due to increase in screw-rod diameter (from 5mm to 6 mm) was in the range of 8% to 24% under the three loading modes. The increase in stiffness due to increase in
screw and rod diameter was found to be nearly same (change in SR less than 1%) in multilevel or intermittent screw fixation. Four fold increase in elastic modulus of the screw and rod system (from TNTZ to CoCr) produced an increase in SR of 25%. Lower elastic modulus material for the connecting rods to allow for the motion at the screw-connecting rod joint decreased SR nominally (1% to 6%). Maximum von Mises stresses and maximum shear stresses were observed at the screw rod junction in the rods and screws at the L5 and S1 level in all loading modes. Neither variation in screw-rod diameter nor placement of the screws at multiple level or intermittent level had any effect on the distribution of stresses in the rods and screws. Screws and rods with different material property showed variation in von Mises stresses in the posterior instrumentations: 50 MPa to 110 MPa with TNTZ; 80 MPa to 150 MPa with Ti; 100 MPa to 180 MPa with CoCr. Variation in the maximum shear stresses in the screws and rods were: 25 MPa to 55 MPa with TNTZ; 35 MPa to 80 MPa with Ti; 50 MPa to 130 MPa with CoCr. However with lower elastic modulus (300 MPa) for the rods, maximum von Mises stresses as well as maximum shear stresses in the posterior instrumentations were only 5 MPa to 20 MPa. In all cases studied here, maximum von Mises stresses were observed at pars interarticularis in levels L4, L5 and S1 on both sides with maximum stress observed at L5 pars. Magnitude of vertebral maximum von Mises stresses did not change with either increase in the size of screw and rod (5mm to 6mm) nor with different screw and rod materials (TNTZ,Ti and CoCr) considered here. Intermittent placement of screw induced maximum von Mises stress of 15 MPa at L5 pars and 6 MPa at S1 pars. Multilevel placement of the screw, on the other hand, induced a maximum von Mises stress of 5 MPa at L4 pars, 15 MPa at L5 pars and 5 MPa at S1 pars. Screws of Ti along with rod of much softer material (300 MPa) produced vertebral von Mises stress of 3 MPa at L5 pars.

**Discussion:** Providing intermittent screw fixation in the posterior instrumentation led to similar stiffer construct as those provided by screw fixation at all levels. Use of comparatively flexible material for the rods did not appreciably reduce the stiffness of the posterior instrumented spine construct from those provided by stiffer rod materials. Nominal increase in spine stiffness was observed by increase in the elastic modulus of the screw-rod material as well as by increasing the size of screw-rod system in the posterior instrumentation. From these results it can be concluded that conventionally used materials and commonly used geometrical dimensions for screw-rod system do stiffen the spine structure. Maximum von Mises stresses as well as maximum shear stresses both in the screw and in the rod were observed at the screw-rod junctions at L5 and S1 levels with largest value at L5 level for all different combinations of screw-rod system considered in this study. Repetitive occurrence of von Misses stresses of magnitude 50 MPa to 150 MPa at the screw-rod junction might cause failure initiation at this site since the yield stress of all the screw-rod combination materials considered in this study are of the order 600 MPa to 800 MPa. Posterior instrumentation with Ti screw and low modulus rod produced a von Mises stress and maximum shear stress of only 20 MPa at the screw-rod junction. From the stress point of view, it may be beneficial to adopt a screw-rod system which allows motion at the junctions. Posterior instrumentation also produced higher stresses in pars interarticularis at L4, L5 and S1 levels with largest value at L5 pars, especially in the model of intermittent instrumentation. Even though the pars stresses were of the magnitude 10 MPa to 15 MPa, these stress concentrations can initiate pars failure at lower lumbar levels due to repeated loading in all the screw-rod combinations studied here. Once again the pars stresses were only of magnitude 3 MPa when a posterior screw-rod system allowed
motion at the junction and thus it may be advantageous to use screw-rod system which allows motion at the junction and multilevel instrumentation. The results suggest that low profile system with 5mm rod diameter is advantageous in spinal reconstruction surgery, considering material property, density of pedicle screws, and usage of polyaxial screws.

**Significance:** Advantage in considering material property, density of pedicle screws, and usage of flexible rod-screws on spinal reconstruction surgery.

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