Stability of a Posterior Total Joint Replacement Prosthesis Under Combined Compression and Shear Forces of Daily Activities

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INTRODUCTION:

The bulk of moment exerted on the trunk during activity is balanced by muscles of the trunk. The lower lumbar segments are then required to resist compressive and shear forces. In vivo studies of lifting indicate the shear force acting on the lower lumbar segments is approximately 20% of the compression force when there is normal muscle activation. This shear force can reach 150-200N for moderate activities. In the presence of muscle dysfunction (e.g. neural deficit, muscle atrophy, injury), the Shear to Compression ratio can be much higher than 0.2:1. These forces are shared by the intervertebral disc, ligaments, and facet joints. This study investigated the role of these structures in resisting anterior slip of L5 on S1 under combined compressive and shear forces in the context of lytic spondylolisthesis.

METHODS:

Seven cadaveric L1-Sacrum specimens were used in the experiment. The specimens were CT scanned with fiducial markers embedded in each vertebra to allow specimen-specific kinematic assessment of 3D vertebral motion.

The sacrum was fixed and L1 constrained to remain above the sacrum. Specimens were tested intact, and after the following stepwise anatomic disruptions: bilateral L5 pars fracture and L5 inferior articular facet process resection, limited denucleation, and resection of posterior ligaments. As a final step, testing was conducted after an appropriately sized total joint replacement (**TJR**) prosthesis was implanted at L5-S1.

Testing consisted of 3 cycles of loading from 0-700N in compression with minimal shear (**Figure 1 A**), approximated by follower load cables across L5-S1, then with Shear to Compression ratios of 1:1, and 1.7:1 (**Figure 1 B**). With 700N of total loading, 1:1 produces equal shear and compressive forces of 495N. The 1:1.7 Shear to Compression ratio produces 600N of shear force and 350N of compressive force. 1:1 and 1.7:1 Shear to Compression ratios simulated a vertical gravity force applied to an L5-S1 segment without load-sharing by muscles when the S1 endplate is inclined at 45 and 60 degrees to the horizontal. The amount of L5-S1 slip (motion of L5 relative to sacrum) was quantified using specimen-specific kinematic assessment.

RESULTS:

In compression with minimal shear (follower load), no significant amount of anterior slip was created by application of 700N in the intact state or any other state ($P>.05$). Statistically significant anterior slip was created with Shear to Compression ratios of 1:1 (S=495N, C=495N) and 1.7:1 (S=600N, C=350N).

L5 inferior facet resection resulted in significantly higher L5 slip than the intact segment under shear loading ($P<.05$), reaching 1.9±0.9mm at 700N force with a Shear to Compression ratio of 1.7:1 (**Figure 2**)**.** L5 anterior slip tended to increase with increasing Shear to Compression ratio ($.05<P<.10$). The L5-S1 segment after TJR implantation demonstrated good resistance against shear forces limiting the L5 slip to below 2mm or less than 5% of S1 endplate width.

DISCUSSION AND CONCLUSION:

The surgical technique for implanting this posterior TJR prosthesis disrupts the posterior elements and intervertebral disc that normally resist shear and compression forces acting on the segment during activities of daily living. With the implanted posterior TJR prosthesis L5 slip on S1 averaged below 2mm (<5% slip) even under a high and possibly supraphysiological Shear to Compression ratio of 1.7:1. We believe restoration of sagittal alignment across L5-S1 and convergence of the left and right components of the TJR prosthesis improve L5 resistance to anterior shear motion.

Figure 1A

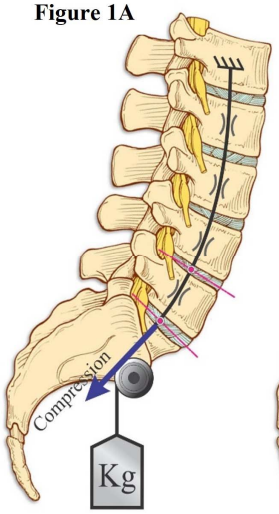

Figure 1B

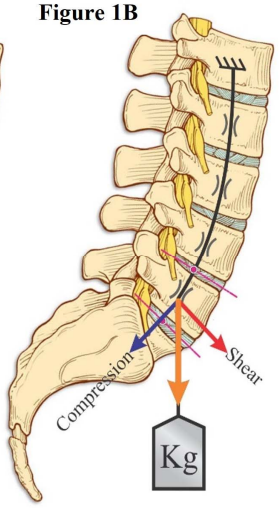

Figure 2