Facet Joint Loading After One-, Two-, and Three-Level Keeled Cervical Disc Arthroplasty

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INTRODUCTION: Compared to fusion, Cervical Disc Replacement (CDR) can reduce compensatory Range of Motion (ROM) at adjacent levels, improve kinematics at the surgical site and increase/restore intervertebral disc height which can result in reduced loading at the facet joint. Despite the success of CDR in improving ROM, reports of facet degeneration have been cited. ROM and associated facet forces can be influenced by prosthesis design, implant height and endplate positioning. It should be recognized that increased ROM at the expense of detrimental facet loading can be a precursor to facet pathology and therefore result in adverse biomechanical loading conditions that may exacerbate adjacent segment pathologies. The purpose of this study was to evaluate effects of multi-level CDR on corresponding facet forces. Further, it was surmised that continued implantation at inferior and superior levels could mitigate any altered facet loading conditions due to the index implantation.
METHODS: Seven human cervical spines (C2-C7, age range: 38 to 66 years) were secured in aluminum sleeves with resin. To acquire the facet forces, 0.2 mm thick flexible thin film sensors (FlexiForce A201, Tekscan, Inc.) were inserted into one facet joint at (C4-C5), (C5-C6) and (C6-C7) using a superior arthrotomy. Sensors were secured into position using an adhesive on the exterior surface of the sensor and capsule. Specimens were inserted into a testing fixture permitting flexion, extension, and lateral bending without disruption of specimen orientation and were subjected to cyclic loading (TA 3300, TA Instruments, Figure 1). A 3 mm deflection was applied to the central (index) vertebra at a rate of 0.1 Hz for 20 cycles in each loading mode with data collection at 40 Hz. Testing conditions included the intact specimen followed by sequential CDR (Figure 2, with a keeled baseplate at the index (C5-C6), inferior (C6-C7), and superior (C4-C5) levels with repetition of the loading regimen between implantations. Sensor output was converted to force using sensor specific calibration curves. For each condition/loading mode, facet forces were normalized using minimum force during the loading mode and reported as the (Max/Min) force ratio. A 1-way ANOVA with Dunnett's post-hoc tests for comparison to intact specimen response was used to infer statistical differences between implantations within each loading mode (Prism 9.4, Graphpad). Significance was set at $P<0.05$.
RESULTS: In flexion, compared to the intact specimens, all three vertebral levels displayed a non-significant but reduced (Max/Min) force ratio following a one-level implantation at (C5-C6) ($P>0.65$, Figure 3A). In extension, the (Max/Min) force ratios across all levels and surgical conditions were not statistically different from the corresponding intact conditions and locations ($P>0.66$, Figure 3B). Loading in lateral bending resulted in reduced, though not statistically different force ratios across implantation sites (Figure 3C). Sequential implantations inferior and superior to the index level displayed comparable or non-significant reductions of the facet ratios regardless of implantation level or loading mode ($P>0.6508$ for all).
DISCUSSION: Based on this number of specimens, implantation of this keeled total disc replacement device at the index level does not statistically alter contact in the facet joints regardless of one-, two- or three-levels of implantations. The (Max/Min) force ratios at all levels under all implantation conditions and loading modes were comparable to or reduced (though not statistically) as compared to the intact condition. Clinically, one may be able to perform multiple level implantations without unduly overloading the facet joints proximal or distal to the central index level. Continued implantation superior and inferior to the index level did not reveal statistically elevated facet force ratios. As with all computational and experimental studies, the current investigation study is limited by use of mechanical testing protocols where, yet unknown true values related to muscle activation and response to loading can be prescribed. The hypothesis that multi-level CDR does not unduly alter facet force ratios was substantiated. The secondary aspect of the hypothesis considering the possibility of increased compensatory facet forces due to additional insertions was also verified as exhibited by non-significant changes in facet forces. Implantation of this keeled disc replacement device at the index, inferior and superior levels does not statistically alter contact in the facet joints up to three-levels of implantations.
SIGNIFICANCE/CLINICAL RELEVANCE: Clinically, one may be able to perform multiple level implantations without unduly overloading the index or adjacent facet joints.

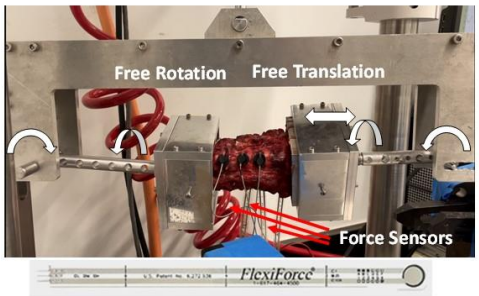

Figure 1. (Top) Testing apparatus permitting coupled motion during dominant loading in flexion, extension, and lateral bending for intact, one-, two-, and three-level implantations. (Bottom) Thin film force sensor.

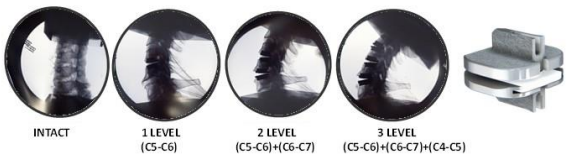

Figure 2. Testing was performed for Intact, Index (C5-C6), Inferior (C6-C7) and Superior (C4-C5) implantations using a keeled disc replacement.

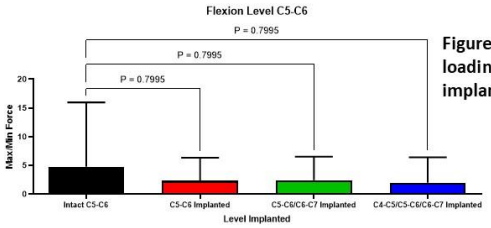

Figure 3A. No elevated facet loading in flexion due to implantations.

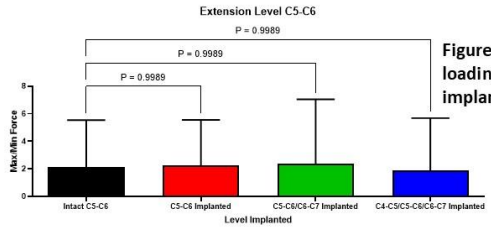

Figure 3B. No elevated facet loading in extension due to implantations.

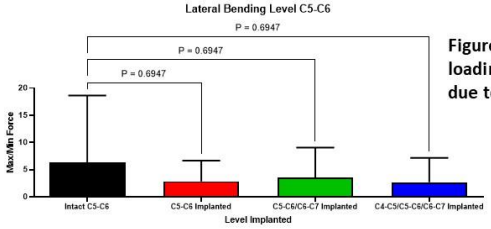

Figure 3C. No elevated facet loading in lateral bending due to implantations.