**In Vivo Changes in Dynamic Adjacent Segment Motion Three Years After One- and Two-Level Cervical Arthrodesis**

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**INTRODUCTION:** The etiology of adjacent segment disease (ASD) after cervical arthrodesis remains unknown. Cadaveric biomechanical studies repeatedly demonstrate increased motion and stress at adjacent segments immediately following anterior cervical discectomy and fusion (ACDF) with two-level fusions exacerbating these effects. However, studies evaluating in vivo adjacent segment range of motion (ROM) are far less conclusive, with some studies reporting changes and others demonstrating no change in adjacent segment motion ROM years after the initial surgery. Additionally, all prior in vivo studies have limited their measurements to static end-range positions during flexion-extension, thus failing to evaluate axial rotation or mid-range motion which is where patients spend nearly all their time. Therefore, the aim of this study was to assess the longitudinal effects of one- and two-level cervical arthrodesis on adjacent segment end-range and mid-range motion during dynamic flexion-extension and axial rotation movements. It was hypothesized that adjacent segment motion would be greater 3 years post-operatively compared to before surgery, and that increases in adjacent segment motion will be greater after two-level compared to one-level arthrodesis. METHODS: Patients scheduled to receive one-level C56, two-level C456, or two-level C567 provided informed written consent to participate in this ongoing IRB-approved study. Patients completed pre-surgical (PRE), 1-year post-surgical (1YR-POST), and 3-years post-surgical (3YR-POST) testing while a group of asymptomatic, age-matched controls were also tested once. On each test day, participants sat upright with their head in the neutral position for a single static image, then performed 3 trials of full range of motion (ROM) flexion/extension (flex/ext) of their head and neck followed by 3 trials of full ROM axial rotation while synchronized biaxial radiographs of the cervical spine were collected at 30 images/for 3 seconds each trial. Three-dimensional vertebral motion was calculated using a previously validated model-based tracking technique that matched digitally reconstructed radiographs generated from subject-specific bone models (obtained from CT) to the radiographs with an accuracy of 0.35mm for translation and 1.1° for rotation. Head motion was synchronized recorded with the biaxial radiography using traditional motion capture using 4 markers placed on the head and 4 markers placed on the thorax. End-range ROM was calculated using the maximum intervertebral flexion and extension from all three flexion-extension and axial rotation trials and the maximum left and right axial rotation from all three rotation trials. Mid-range ROM was calculated as the intervertebral motion that occurred within 20° of neutral head orientation during flexion/extension and axial rotation. All components of motion were normalized to the static neutral position PRE. The superior adjacent C45 segment was compared between the two-level C56 arthrodesis group and the one-level C56 arthrodesis group, while the inferior adjacent C67 segment was compared between the two-level C456 group and the one-level C56 arthrodesis group. Two-way ANOVA was used to identify differences in intervertebral ROM, head ROM, and mid-range ROM over time (PRE, 1YR-POST, and 3YR-POST) and between groups (one-level and two-level arthrodesis). A one-way ANOVA was used to identify differences in head ROM and intervertebral ROM between arthrodesis groups and controls at each test date. Significance was set at p < 0.05 for all statistical tests with a post-hoc Bonferroni correction for multiple comparisons.

**RESULTS:** Data from 27 of the 65 patients who have completed testing on all three dates (11 who received one-level C56 (4M/7F, 46.9 ± 5.8 years), 5 who received two-level C456 (3M/2F, 49 ± 8.2 years), and 11 who received two-level C567 (4M/7F, 49.2 ± 9.6 years)), and 22 asymptomatic, age-matched controls (12M/10F, 47.6 ± 8.6 years) were evaluated in this interim analysis of 618 trials. Mid-range axial rotation in the superior and inferior adjacent segments increased from PRE to 3YR-POST in patients who received two-level arthrodesis (p = 0.015 and p = 0.05, respectively) (Figure 1A, 1B). A significant main effect of increased axial rotation end-range ROM in the adjacent segments (p = 0.037) was found, however, post-hoc tests were non-significant for both arthrodesis groups (all p > 0.196). A significant main effect of increased flexion-extension mid-range ROM over time after surgery was found (p = 0.041), however, the post-hoc tests were non-significant for either arthrodesis group (all p > 0.131) (Figure 1C, 1D). The control group had more head flex/extension ROM than patients who received either one-level or two-level arthrodesis, and controls had more head axial rotation ROM than patients who received two-level arthrodesis (all p < 0.05). There were no differences in head ROM between the arthrodesis groups at any time point (all p > 0.264). DISCUSSION: The main findings were that superior adjacent segment mid-range ROM and inferior adjacent segment end- and mid-range ROM during axial rotation were greater 3 years post-operatively compared to pre-operatively after two-level arthrodesis. However, despite the apparent trend of increased adjacent segment motion, no changes in adjacent segment motion were detected during rotation after single-level arthrodesis or during flexion-extension after either procedure. These results suggest that axial rotation may be more sensitive than flexion/extension for detecting early changes in adjacent segment motion after one- and two-level cervical arthrodesis, especially given the discordant results from prior short-term in vivo follow-up studies evaluating only flexion/extension. The results of this study are limited to C56, C456, and C567 arthrodesis and have relatively short follow-up time of 3 years post-surgery. Longer-term follow-up may reveal additional changes in adjacent segment ROM. SIGNIFICANCE: Mid-range ROM and axial rotation appear to be more useful than end-range ROM or flexion/extension for detecting midterm changes in adjacent segment motion after cervical spine arthrodesis, which may have important implications in understanding the pathophysiology of developing ASD.


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**Figure 1:** (A) Superior and (B) inferior adjacent segment axial rotation mid-Rom. (C) Superior mid-range ROM and (D) inferior flex/extension end-range ROM. Red bars indicate differences in the 2-level arthrodesis group between PRE and 3YR-POST. Trends in increased adjacent segment motion during flexion-extension(C and D) were not significant.