Mid-Range Motion is More Sensitive Than End-Range Motion For Detecting Changes Over Time in Adjacent Segment Motion After Anterior Cervical Arthrodesis

Clarissa M. LeVasseur,[1,2] Samuel W. Pitcairn,[1] Jeremy D. Shaw,[1,2] William F. Donaldson,[1,2] Joon Y. Lee,[1,2] and William J. Anderst[1]
[1]Department of Orthopaedic Surgery, [2]Orland Bethel Family Musculoskeletal Research Center (BMRC), University of Pittsburgh, Pittsburgh, PA
Email of Presenting Author: cll100@pitt.edu

Disclosures: LeVasseur (N), Pitcairn (N), Shaw (N), Donaldson (N), Lee (N), Anderst (N)

INTRODUCTION: The etiology of adjacent segment disease (ASD) after cervical arthrodesis remains unknown. Biomechanical studies on cadavers consistently show increased motion and stress at adjacent segments immediately following anterior cervical discectomy and fusion (ACDF), with greater effects observed in two-level compared to one-level fusions.[1] However, *in vivo* studies indicate adjacent segment range of motion (ROM) increases in some individuals but decreases in other individuals 1 to 2 years after ACDF.[2-4] This prospective study aimed to evaluate 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 up to 3 years after ACDF. Our hypotheses were that (1) adjacent segment motion would increase from before surgery to 1-year post-surgery to 3-years post-surgery; (2) the increase in ROM would be greater following two-level arthrodesis compared to one-level arthrodesis; and (3) adjacent segment motion after arthrodesis would be greater than in the corresponding motion segments of age-matched asymptomatic controls.

METHODS: Patients scheduled to receive one-level C56, two-level C456, or two-level C567 arthrodesis participated in this IRB-approved study. Pre-surgical (PRE), 1-year post-surgical (1YR-POST), and 3-year post-surgical (3YR-POST) testing were conducted on patients. Data was collected once for age-matched asymptomatic controls. On each test day, participants underwent static imaging while sitting upright and then performed 3 trials each of full flexion/extension and axial rotation ROM while synchronized biplane radiographs of the cervical spine were collected at 30 images per second. Head motion was tracked using conventional motion capture tracking 4 retroreflective markers placed on the head and 4 markers placed on the torso. Three-dimensional vertebral motion was calculated using a validated model-based tracking technique that matched digitally reconstructed radiographs, generated from patient-specific CT scans, to the biplane radiographs with accuracy better than 1mm and 1°.[5] End-range ROM and mid-range ROM, which was defined as head motion within 20° of the neutral head position[3,4], were calculated. Changes in adjacent segment motion within each arthrodesis group over time (PRE, 1YR-POST, 3YR-POST) were analyzed using Mixed Model ANOVA (Group x Test date), with the interaction testing for differences between arthrodesis groups in the change in ROM over time. One-way ANOVA was used to identify differences in intervertebral ROM between arthrodesis groups and controls on each test date. Significance was set at $p<0.05$ with a post-hoc Bonferroni correction for multiple comparisons.

RESULTS: Forty-seven of the 57 enrolled patients completed testing on all three dates (21 received one-level C56 (9M/12F, 47.4±8.0 years), 7 received two-level C456 (4M/3F, 49.6±7.0 years), and 19 received two-level C567 (8M/11F, 48.9±7.8 years). 22 asymptomatic, age-matched controls (12M/10F, 47.6±8.6 years) were also included in this analysis. While group average end-range adjacent segment motion increased slightly over time (Figure 1A,B), only the axial rotation end-range at the superior adjacent motion segment following two-level arthrodesis significantly increased from PRE to 3YR-POST ($p=0.03$, Figure 1B). Midrange flexion/extension ROM increased from PRE to 1YR-POST and 3YR-POST at the inferior-adjacent motion segment following one-level arthrodesis (all $p<0.017$, Figure 1C), and the post-surgical mid-range motion was larger than age-matched controls (all $p<0.03$). Mid-range axial rotation ROM increased from PRE to 1YR-POST following one-level arthrodesis at both adjacent motion segments (all $p<0.04$, Figure 1D), and from PRE to 3YR-POST following two-level arthrodesis at both adjacent motion segments (all $p<0.05$, Figure 1D). No differences were found in adjacent segment end-range or mid-range ROM between one- and two-level arthrodesis (all $p>0.06$), and no interaction between the number of levels fused and test dates were found (all $p>0.19$).

DISCUSSION: Our hypotheses were only partially supported, with (1) some components of end-range and mid-range adjacent segment motion increasing pre- to post-surgery, but no changes were observed from 1YR-POST to 3YR-POST; (2) no differences observed in the change in adjacent segment ROM between one- and two-level arthrodesis; (3) only the inferior adjacent mid-range motion after one-level arthrodesis being greater than the corresponding motion segment in controls. Theses *in vivo* results at 1 and 3 years after arthrodesis contradict *in vitro* studies that consistently show an increase in adjacent segment motion of 20% or more after arthrodesis.[6,7] The small increases in adjacent segment motion during head mid-range motion may have a cumulative effect on adjacent segment disc loading over time, potentially exacerbating adjacent segment disc degeneration. The results of this study are limited to C56, C456, and C567 arthrodesis at mid-term follow-up (3 years post-surgery). Longer follow-up may reveal additional changes in adjacent segment ROM.

SIGNIFICANCE: The current standard of care imaging for assessing adjacent segment motion after arthrodesis is full ROM in sagittal plane flexion/extension. Mid-range motion during flexion/extension and rotation, which comprises most activities of daily living, appears to be more sensitive than end-range flexion/extension motion for detecting short-term effects of arthrodesis on adjacent segment motion.

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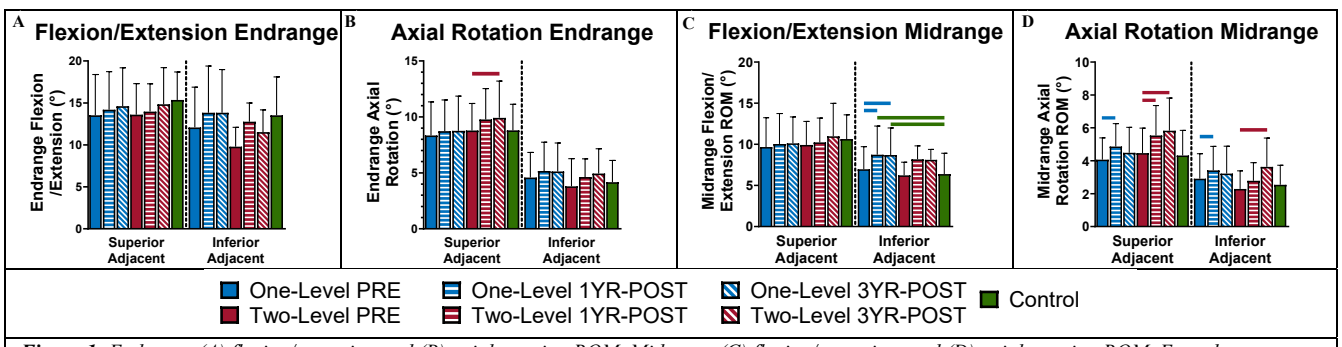

***Figure 1**: Endrange (A) flexion/extension and (B) axial rotation ROM. Midrange (C) flexion/extension, and (D) axial rotation ROM. Error bars indicate ±1SD. Blue and red bars indicate differences between test dates for one and two-level groups, respectively, while green bars indicate differences from controls.*