Changes in Adjacent Segment Disc Strain 3 Years After Cervical Arthrodesis

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INTRODUCTION: The incidence of anterior cervical discectomy and fusion (ACDF) is projected to increase by 13.3% each year in the U.S, between the years 2020 and 2040, costing between $1.1 billion and $2.6 billion by 2040[1]. Approximately 25% of ACDF patients will develop symptomatic ASD requiring a second surgery within 10 years[2]. There is controversy regarding the exact cause of ASD. One theory is that the arthrodesis leads to increased range of motion in the adjacent segments following ACDF, which leads to increased loads (stress and strain) on the adjacent segments[3]. However, it is unknown if disc loads increase *in vivo* after arthrodesis. The objectives of this study were to determine the effects of ACDF on adjacent segment disc deformation (strain) during full range of motion head movements. It was hypothesized that adjacent segment disc compression, distraction, and shear strain increase from pre- to post-surgery, and that adjacent segment disc strain in patients after ACDF would be greater than in corresponding discs of asymptomatic controls.

METHODS: All participants provided informed written consent to participate in this ongoing IRB-approved study. Surgical participants received a C456, C56, C67, or C567 ACDF, were below the age of sixty pre-surgery, and completed pre-surgery (PRE), 1 year post-surgery (1YR-POST), and 3 years post-surgery (3YR-POST) testing. All control participants were healthy, asymptomatic individuals with no history of neck surgery, chronic neck pain or diagnosis of osteoporosis, and were age, sex, and BMI matched to at least one of the surgical patients. Controls were tested once. On each test day, all participants sat upright with their head in neutral position for a single static image, then performed 3 trials of full range of motion (ROM) flexion/extension of their head, followed by 3 trials of full ROM axial rotation while synchronized biplane radiographs of the cervical spine were collected at 30 images/s for 3 seconds each trial. Three-dimensional vertebral motion was calculated using a previously validated model-based tracking technique that matched digitally reconstructed radiographs created from subject-specific bone models (obtained from CT) to the radiographs with an accuracy of 0.2mm to 0.44mm for measuring anterior and posterior disc height, respectively[4]. Head motion was synchronously recorded using traditional motion capture by placing 4 markers on the head and 4 markers on the torso. Each intervertebral disc was modeled by a series of 10 concentric rings of line segments connecting the adjacent endplates. The discs were divided into five regions based on endplate geometry (anterior, lateral, posterior-lateral, posterior, and nucleus)[5]. Distances between adjacent endplates during dynamic trials were used to calculate regional disc deformation relative to the static trial collected on the first visit (Figure 1). Compression, distraction, and shear deformation at the adjacent segment in each of the five disc regions were interpolated to every 10° of head flexion/extension or every 15° of axial rotation and averaged across the three trials. A linear mixed-effects analysis was used to identify differences in disc strain over time (PRE to 1YR POST to 3YR POST), as well as to identify differences in disc strain between controls, one-level arthrodesis patients, and two-level arthrodesis patients at corresponding discs, with significance set at $p<0.05$ for all tests.

RESULTS: Data from 22 controls (10F, age 47±7.9 years, BMI: 31.0±5.4 kg/cm^2) and 28 of 65 patients (16F, age 48.3±7.6 years, BMI: 31.1±5.3 kg/cm^2) who have completed 3YR-POST testing are included in this interim analysis. Patients included 6 C456, 11 C56, and 11 C567 arthrodesis patients. During flexion/extension, no differences in disc strain were found in patients over the three test dates (all $p > 0.217$). However, during axial rotation, distraction increased in the C45 disc superior to the arthrodesis at 1YR-POST (all $p<0.011$) and at the C67 disc inferior to the arthrodesis at 1YR-POST ($p=0.041$) and 3YR-POST ($p=0.044$) in comparison to PRE. Also during axial rotation, compression increased at the C67 disc inferior to the arthrodesis at 3YR-POST (all $p<0.001$) and shear increased at both the C45 ($p=0.043$) and C67 ($p=0.043$) discs from PRE to 3YR-POST. When comparing disc strain in discs adjacent to one-level and two-level arthrodesis to corresponding discs in controls, during flexion/extension, the C45 disc superior to arthrodesis was more compressed than in controls at PRE for both one-level (all $p<0.023$) and two-level arthrodesis (all $p<0.048$), and at 1YR-POST (all $p<0.002$) and 3YR-POST (all $p<0.002$) for two-level arthrodesis. Similarly, the C67 disc inferior to the arthrodesis was more compressed in one-level patients PRE (all $p<0.032$), and in two-level patients at 1YR-POST (all $p<0.026$), while the adjacent C45 disc was more distracted in discs adjacent to one-level arthrodesis at 1YR-POST (all $p<0.009$) and 3 YR-POST (all $p<0.002$) in comparison to controls. Shear deformation was also greater in the C67 disc inferior to one-level arthrodesis at PRE (all $p<0.041$), 1 YR-POST (all $p<0.002$), and 3 YR-POST (all $p<0.002$) compared to controls. During axial rotation, compression at the C67 disc inferior to arthrodesis was greater in patients who received one-level arthrodesis at 3YR-POST ($p=0.013$) and in patients who received two-level arthrodesis at 1YR-POST (all $p<0.032$) and 3YR-POST (all $p<0.003$) compared to controls. Also during axial rotation, distraction at the C45 disc superior to arthrodesis was greater in patients who received one-level arthrodesis than in controls at 1YR-POST ($p=0.010$) and 3YR-POST (all $p<0.015$). Finally, shear deformation during rotation was greater in the C45 disc superior to arthrodesis in patients who received two-level arthrodesis in comparison to controls at 3YR-POST (all $p<0.026$) and in the C67 disc inferior to arthrodesis in patients who received one-level arthrodesis at 1YR-POST (all $p<0.043$) and 3YR-POST ($p=0.043$) in comparison to controls.

DISCUSSION: These interim results suggest that changes in adjacent segment disc deformation from PRE to 3YR-POST are more easily detected during axial rotation than during flexion/extension. Disc strain was higher in patients than in controls in all cases where significant differences in disc strain were observed between groups, suggesting that adjacent segment disc strain is consistently increased in patients after arthrodesis compared to asymptomatic controls. Longer-term follow-up is needed to determine if these early changes in disc strain are associated with symptomatic adjacent segment disc degeneration. Data for the entire cohort is needed for a more detailed analysis into which head positions (end-range, midrange) are associated with increased adjacent segment disc strain after arthrodesis.

SIGNIFICANCE: It may be more advantageous to image the cervical spine during axial rotation, rather than the current clinical standard of flexion/extension, to identify increases in disc loading over time after cervical arthrodesis.

REFERENCES: 1) Neifert et al., World Neurosurgery 2020. 2) Cho et al., JAAOS 2013. 3) Xu et al., J Orth. Surg. Res. 2018. 4) Anderst et al., Spine 2011. 5)Anderst et al., *ABME*, 2015.

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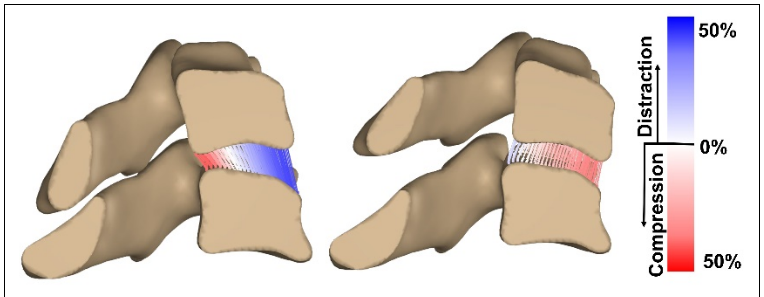

Figure 1: Cross section of two vertebrae and disc at maximum extension (left) and flexion (right) with the disc color-coded according to compression-distraction strain.