A Novel Laboratory Model of Postural Consequences of Cervical Sagittal Imbalance - Biomechanical Data Can Help Clinical Practice

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Introduction: A physiologic sagittal alignment of the cervical spine, including the ability to maintain a level gaze, is essential to maintaining functionality during activities of daily living. Consequently, cervical sagittal imbalance has been linked to poor health-related quality of life due to disabling symptoms of neck pain and neurological deficit. Forward position of the head relative to the shoulders (forward head posture [FHP]) is a measure of global cervical imbalance, measured on a lateral x-ray as C2-C7 horizontal offset (C2-C7 Sagittal Vertical Alignment or SVA) exceeding physiologic normative value. This may result from kyphotic alignment of one or more cervical segments as well as mal-alignment of thoracolumbar spine. This laboratory study measured the effects of increasing FHP severity and change in T1 sagittal tilt on compensatory angular and translational repositioning of each vertebra needed to maintain horizontal gaze. We hypothesized that increasing forward head posture severity will cause flexion of the lower cervical segments and hyper-extension of the C0-C1-C2 segments, which has implications to sub-occipital neck pain, muscle fatigue, and headache.

Methods:

Seven human cadaveric cervical spines (Occiput-T1) were used (age: 42.9±16.1 years old). The specimens were placed in the test apparatus (Fig. 1). The T1 vertebra was anchored to a tilting and translating base. The occiput could move vertically but its angular orientation was constrained to ensure horizontal gaze regardless of simulated imbalance. A 23° T1 sagittal tilt and 2.0 cm anterior offset from the head’s gravity line to C7’s posterior-superior corner represent normative values. The anterior overhang was set by translating the base. The translation of the base was measured using both a vernier scale and an infra-red tracking marker. Sagittal tilt of T1 was set using the tilting stage on the base; the tilt angle was measured using an inclinometer attached to the stage. The tilting mechanism was designed such that the axis of rotation was positioned at the center of the superior endplate of T1. The mechanism could be locked during translation stage motion and was under the control of a gear motor which produced a constant angular velocity during the adjustment of thoracic tilt. A linear bearing at the top of the apparatus allows the rod connected to the occiput to translate freely in the vertical or cranial-caudal plane. The bearing resists shear loads applied perpendicular to the rod axis. The rod also provides a means to apply a compressive load to the specimens. A 5kg mass was attached to the rod to mimic head weight, with the gravity line acting through the anterior margin of the external auditory meatus. The tilting mechanism and specimen cup was mounted on a six axis load cell. The load cell was then mounted on the translating base and was used to measure the reaction forces and moments during the experiments. The load cell was tared with the specimens in the nominal posture in the apparatus.

Each spinal level was instrumented with infra-red optoelectronic tracking markers, which allow 3D kinematic tracking of each spinal segment during the experiment. FHP magnitude (C2-C7 SVA) and T1 tilt were varied individually and in combination without exceeding pre-set limits on moments to prevent tissue damage. Angular and translational motions of individual vertebrae (C1-C7) were measured and used to calculate: angles across C0-C2 and C2-C7, and C2-C7 SVA, a measure of global cervical balance.

Results:

In the laboratory model of cervical sagittal mal-alignment, reciprocal postural compensation was observed in the upper and lower cervical spine. At all T1 sagittal tilt angles tested, an increase in anterior overhang (i.e. C2-C7 SVA) caused flexion in the lower and extension in the upper cervical segments (Fig. 2).

The transition between flexion and extension occurred at approximately the C2-C3 to C3-C4 motion segments. In all specimens, angular compensation in the upper cervical segments began in the motion segment closest to the transition zone. Adjacent segments were recruited in turn as the motion segments approached motion limits. For example with increasing forward head position, C0-C1 segmental angle does not change until C1-C2 angular motion plateaus. The reciprocal postural compensation and sequential recruitment of motion segments was also observed in the experiments where anterior overhang was held.
constant and T1 tilt angle was varied. The sub-occipital (C0-C1-C2) lordosis increased while C2-C7 lordosis decreased (Fig. 2). A linear regression analysis of the calculated angles across C0-C2 & C2-7, C2-C7 SVA (anterior overhang) and the measured T1 sagittal tilt were used to develop a predictive model for C0-C2 angle. The predictive model equation is: (C0-C2 angle) = 16 + 0.20 X_1 + 0.62 X_2 - 0.59 X_3; R^2=0.89, p<0.001.

Discussion:

This is the first study establishing a cause-&-effect relationship between radiographic measures of FHP, T1 tilt and sub-occipital lordosis. Increasing FHP severity hyper-extends C0-C1-C2 when patient attempts to maintain level gaze. Postural compensation involving sub-occipital hyper-extension may lead to sub-occipital extensor muscle fatigue and headache, and increased posterior column loading causing pain. The regression model predicted that reduction of T1 tilt and normalization of C2-C7 lordosis & SVA will reduce C0-C2 hyper-extension.

Significance:
These findings may help plan corrective strategy in patients suffering neck pain, which may be attributed to sagittal plane mal-alignment, with C0-C2 hyperextension secondary to hyper-kyphotic T1 tilt.

Acknowledgments:

References:
Head Weight 50N

Occiput

Gravity Line

C2

C3

C4

C5

C6

C7

T1

Overhang

Ex-Fix to Simulate fusion with variable alignment

Pivot to alter kyphosis of upper Thoracic spine (T1 tilt)

6-Axis Load Cell
Table 1: Coefficients of the Predictive Model

<table>
<thead>
<tr>
<th>Independent variable</th>
<th>Regression coefficient</th>
<th>p-level</th>
<th>Standardized coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>X1: C2-C7 SVA</td>
<td>0.20</td>
<td>&lt;0.001</td>
<td>0.309</td>
</tr>
<tr>
<td>X2: T1 tilt</td>
<td>0.62</td>
<td>&lt;0.001</td>
<td>0.536</td>
</tr>
<tr>
<td>X3: C2-C7 angle</td>
<td>-0.59</td>
<td>&lt;0.001</td>
<td>-0.851</td>
</tr>
</tbody>
</table>
Figure 2. Postural compensation with change in SVA