The neutral posture of the cervical spine is not unique

Robyn S. Newell, Peter A. Cripton, Jean-Sébastien Blouin, John Street, Gunter P. Siegmund

I. INTRODUCTION

Knowing the posture of the cervical spine immediately prior to a head-first impact is critical to studying and ultimately preventing cervical spine injuries. For instance, during *ex vivo* impact testing the cervical spine is often manipulated into various static postures to study the resulting injuries. One such postural manipulation consists of changing the overall neck angle by setting the relative horizontal position (i.e. eccentricity) of the superior and inferior ends of the cervical spine prior to impact [1-2]. However, catastrophic injury to the cervical spine typically occurs in a dynamic environment (such as in a car crash or sports impact) and thus motion of the spine could occur prior to injury. Indeed, efforts to pre-position the eccentricity of a cadaver spine prior to impact testing implicitly assume the following: 1) vertebral alignment and head angle at the same eccentricity are the same in a resting and dynamic condition, 2) spine alignment does not depend on the direction from which it approached this eccentricity, and 3) muscle forces required to pre-position the spine have negligible effects on the spinal alignment. These three assumptions have not been verified *in vivo*, and thus it is important to quantify what differences, if any, exist between resting and dynamic alignment of the cervical spine. The overall aim of this study was to assess the assumptions inherent to simulating a resting postural alignment. Our specific hypotheses were that the alignment of the spine and muscle activations would be different in resting and dynamic "neutral" posture, and that the difference between these postures would depend on the direction of motion used to arrive at the neutral posture. To address the fact that some cervical spine injuries during rollover crashes occur while upside down, we tested our hypotheses in both the upright and inverted postures.

II. METHODS

Eleven human subjects (6 female and 5 male) were seated in a custom-built inversion device and secured with a 5-point harness. Alignment of the cervical spine was captured using fluoroscopy and muscle activation levels were recorded using electromyography (EMG). First, subjects were instructed to sit in a comfortable, upright, relaxed posture (Upright-Relaxed) for 2 seconds. Then subjects were instructed to perform dynamic flexion and extension movements of their head and necks while upright and upside-down. Subjects started in full extension, moved to full flexion, and then returned to full extension over six seconds. The Upright-Resting position was used to compare postural measures of the head and spine as it moved through the neutral position during the flexion/extension task. We defined the "neutral" neck posture during the flexion/extension task as the posture where the neck's eccentricity (horizontal displacement between the top of C1 and the bottom of C7) was closest to that measured in the Upright-Relaxed posture.

The postural measures included the cervical curvature index, the absolute vertebral angles (C1 through C7), and the head angle. Muscle activity was measured for eight neck muscles (sternohyoid, sternocleidomastoid, trapezius, levator scapulae, splenius capitis, semispinalis capitis, semispinalis cervicis and multifidus) using a combination of surface and fine-wire electrodes. The postural metrics and muscle activation levels were assessed in the Upright-Relaxed task and as subjects passed through the neutral neck position in both directions (flexion and extension) and in both orientations (upright and inverted): Upright-Flexion, Upright-Extension, Inverted-Flexion and Inverted-Extension. One-way repeated measures ANOVA was used to compare the curvature indices, head and vertebral angles, and EMG levels between the five conditions. Post-hoc Dunnett's tests were used to compare each dynamic trial (Upright-Flexion, Upright-Extension, Inverted-Flexion, and Inverted-Extension) to the Upright-Resting trial (statistical significance was set at p=0.05). The postural metrics and muscle activation levels are presented as means and 95% confidence intervals (95%CI).

R. S. Newell is a PhD student candidate in Biomedical Engineering at the University of British Columbia in Biomedical Engineering (tel: 1-604-675-8845, email: newellr@interchange.ubc.ca). G. P. Siegmund, is President of MEA Forensic Engineers & Scientist and an Associate Adjunct Professor in the School of Kinesiology at the University of British Columbia.

III. INITIAL FINDINGS

The curvature index as the neck passed through neutral was significantly higher in Upright-Flexion (4.2%, 95%CI: 2.0-6.4%), Upright-Extension (3.7%, 95%CI: 1.5-5.9%), and Inverted-Extension (3.4%, 95%CI: 1.3-5.6%) compared to Upright-Relaxed (1.9%, 95%CI: 0.7-3.1%). The angle of the Frankfort plane was significantly different during Inverted-Extension compared to the Upright-Relaxed (16.0° more extended, 95% CI: 4.9-27.1°, $p<0.001$). In Upright-Flexion, the upper cervical spine (C1 through C3) was more extended and the lower spine (C5 to C7) was more flexed than in Upright-Relaxed (multiple $p<0.005$) (see Figure 1). The same was true for Upright-Extension, except that C5 was not significantly different. During Inverted-Extension, C2 and C3 were more flexed ($p=0.048$ and $p=0.007$, respectively), while C7 was more extended ($p=0.0007$). No differences in absolute vertebral angles were found for Inverted-Flexion.

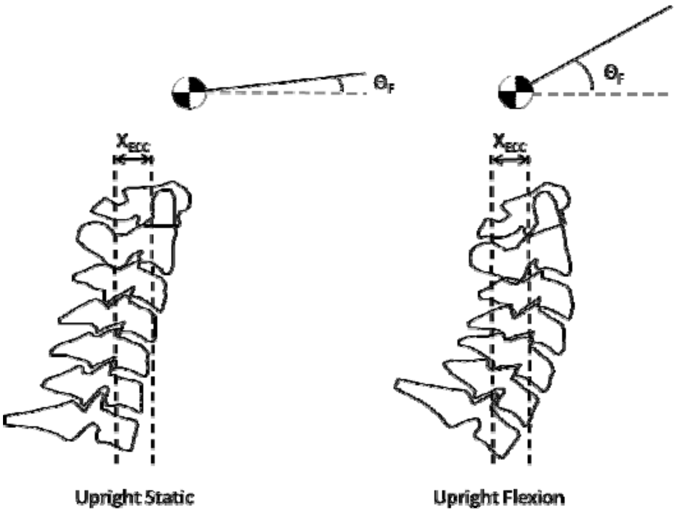

Figure 1: Exemplar neutral postures
The vertebral alignment for one subject for Upright-Resting (left) and Upright-Flexion (right), where the two conditions have identical eccentricities (X_{ECC}). If a force were imparted to the spine from head contact (i.e. head-first impact) the differences in head COM positions, Frankfort plane angles (Θ_F), and vertebral orientations in the two cases would result in a different loading path through the cervical column.

Some of the mean group muscle activation levels (expressed as a percent of maximum voluntary contraction, MVC) during movements through neutral were significantly larger than the muscle activation levels while in the Upright-Resting posture. During Upright-Flexion only the sternohyoid had greater activity ($p=0.0001$), whereas during Inverted-Flexion both the sternocleidomastoid and sternohyoid had greater activity (multiple $p<0.0001$) compared to Upright-Resting. Although statistical differences existed in flexion, the muscle activation levels remained less than 5% of MVC. Activation levels increased in the posterior muscles during Upright-Extension, with semispinalis cervicis (2.5%MVC, 95%CI: 1.2-5.0%, $p=0.004$) having the highest mean activation level. All posterior muscles had higher activation levels during Inverted-Extension: ranging from 2.2% (CI: 0.9-5.5%) in splenius to 6.7% (95%CI: 2.2-20.1%) in levator scapulae (multiple $p<0.005$).

IV. DISCUSSION

Using a comparison of resting and dynamic spine postures at the same eccentricity, we found the following: 1) vertebral alignment (curvature and vertebral angles) and head angle are not the same in a resting and dynamic condition, 2) spine alignment depends on the direction from which it approaches neutral posture (particularly inverted), and 3) muscle activity is present during dynamic motion (particularly inverted). These findings are relevant to basic spine biomechanics as well as *ex vivo* testing where the head and neck are statically (and neutrally) positioned prior to impact, often with no or negligible muscle forces. Moreover, these findings suggest that current cadaveric head-first impact tests may not accurately reflect the cervical spine's state in a dynamic injury environment.

V. REFERENCES

[1] Pintar et al., SAE Technical Paper No. 952722, 1995

[2] Maiman et al, Journal of Neurosurgery, 2002