INTRODUCTION
Studies have shown that females are more likely to experience neck injuries than males. A female neck model is requisite for analysis of gender difference in neck injuries, especially the effect of size, geometry and biomechanical properties. Male neck models have been developed (Vasavada et al., 1998; Chancey et al., 2003), but to our knowledge a female model does not exist. The goal of this study is to develop a musculoskeletal model of the female neck and head system based upon female anatomy from the National Library of Medicine’s Visible Human Female (VHF), and compare the female to male neck models.

METHODS
The VHF subject was 1.65m tall (65th percentile height female) and 59 years old. Although her exact weight is not available, Bajka et al. (2004) estimated her weight from her liver volume, to be about 124-131kg. Her external neck and head size were estimated to be over or around 90th percentile female (Gordon et al., 1989). However most of her vertebrae are in the 40th-60th stature percentile female range for vertebral height and depth (Katz et al., 1975).

Head and neck skeletal anatomy: Computed tomographic (CT) images of VHF skull, vertebrae (C1-T6), ribcage, clavicle, scapula and hyoid bone were traced using image analysis software (3D-doctor, Able Software, Lexington, MA). The biomechanical model (Figure 1a) was built in SIMM (Software for Interactive Musculoskeletal Modeling, Santa Rosa, CA).

Joint kinematics: The visible female was scanned in the supine posture, resulting in a neck posture, which was different from the upright neutral posture. We used a lateral x-ray of a height-matched female subject (1.65m, 48.6kg, similar vertebrae size) in the upright neutral posture (standing) to align the VHF bones to upright neutral (Figure 1b, 1c). This ensured a neutral posture, which fell within the range reported in the literature (Harrison et al., 2004).

The rotation centers of skull and vertebrae were estimated from subjects in which gender was not specified (Amevo et al., 1991) and scaled by the vertebral size of VHF.

Muscle anatomy and force-generating parameters: The muscle volumes were obtained from the reconstruction of 3D muscle surfaces by tracing the color cryosection photographs of VHF. Physiological cross-sectional (PCSA) was obtained by dividing muscle volume by muscle fiber length, which was estimated by calculating the length of a cubic B-spline curve that used least squares approximation.
fitted to the muscle centroids at each slice. Other parameters were scaled from the male neck model.

The origin and insertion of each neck muscle were attached to the same bony landmarks as those of male model and connected by a straight line (Figure 2).

**RESULTS AND DISCUSSION**

The VHF model predicted that the extension moment at the neutral position was 28 Nm, which was larger than experimental data from females (Vasavada *et al.*, 2001). The VHF data were compared to two male models representing a 50th percentile male, where the only difference between those two was that one (“M1”) used PCSA measured from older male and female cadavers (Kamibayashi *et al.* 1998) and the other one (“M2”) used PCSA estimated from *in vivo* MRI of young 50th percentile males (Chancey *et al.*, 2003). The ratio of female model maximum extension moment to “M1” and to “M2” were within the range from the literature (Suryanarayana *et al.*, 2004; Vasavada *et al.*, 2001) (Table 1).

The moment maximum analysis was broken down to two parts: the effect from the peak muscle forces and from the muscle moment arms (Table 1). The peak muscle force is proportional to PCSA. The average PCSA of VHF is close to PCSA obtained from cadaver data and is smaller than that from *in vivo* MRI data. However, even if female PCSA is slightly larger than male, the smaller moment arms result in lower total moment. The smaller moment arms of the female model mainly result from her smaller skeletal structure compared to 50th percentile male. However the slightly different neutral postures and use of straight-line muscle paths could also affect the differences in moment arm.

**Table 1:** The comparisons of maximum extension moment in neutral position among female model (F), *in vitro*-PCSA male model (M1) and *in vivo*-PCSA male models (M2)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Ratio1 (F/M1)</th>
<th>Ratio2 (F/M2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PCSA</td>
<td>1.05</td>
<td>0.74</td>
</tr>
<tr>
<td>Moment arm</td>
<td>0.77</td>
<td>0.77</td>
</tr>
<tr>
<td>Max. Moment</td>
<td>0.84</td>
<td>0.59</td>
</tr>
</tbody>
</table>

It was obvious that we could not scale a male neck model to a female one by a simple ratio, since there were many gender differences in size, geometry and biomechanical properties.

**SUMMARY/CONCLUSIONS**

The results predict lower neck strength in females, even when muscle size is comparable to males, as in this very large female (VHF). The skeletal structure appears to play a very important role in our current straight-line neck model. Gender-specific neck models are necessary for further research.

**REFERENCES**


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