

CERVICAL SPINE GEOMETRY: FEMALE VERTEBRAE CANNOT BE SCALED FROM MALE VERTEBRAE

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INTRODUCTION

It is estimated that whiplash-related trauma resulting from low-speed rear impacts make up approximately 25% of all injuries resulting from automobile accidents (NHTSA). Statistically, females have twice the risk of receiving a whiplash injury as males do in automobile accidents (Mordaka, 2003). Finite element (FE) models of the cervical spine have been used since the 1980's (Brolin, 2004); however, models in which the geometry is described parametrically from easily obtained CT scans do not exist. The development of parametric and anatomically accurate finite element models representative of the human cervical spine for both genders provided the motive for this study.

Basic differences between the male and female cervical spine geometry have been noted in the literature. In studies performed by Katz (1975) and Liguoro (1994), the mean width and height of male vertebral bodies were found to be significantly larger than female vertebral bodies. In 2004, Klinich confirmed the findings of previous studies. However, in all of the cited studies, measurements were taken from lateral x-rays, computed tomography (CT) scanning would yield three dimensional results and more geometric measurements could be made. While knowledge of the differences between the male and female cervical spine exists, it is not documented in sufficient detail to create gender representative FE models.

The objective of this study is to measure the dimensions of the cervical vertebrae (C3-C7) from high fidelity CT images that can then be used to create a parametric finite element model of the cervical spine. A database will be created of the vertebral dimensions at each vertebral level of the cervical spine for both genders. A statistical comparison will also be made between the male and female values to determine which parameters are statistically different.

METHODS

CT scans of the cervical spine of 73 healthy young volunteers (23 female and 50 male) were obtained in digitized format. For each cervical vertebra C3 through C7, 35 parameters were measured describing the vertebral geometry; a total of 175 parameters were measured for each volunteer. The CT image stacks were re-sliced to allow measurements on four different planes. All of the measurements were made in ImageJ (ImageJ 1.34, National Institutes of Health, USA) by a single researcher trained in reading cervical spine CT images to minimize error.

A statistical t-test procedure was used to compare the sample means of the two groups (male vs. female) for each of the 175 parameters in order to test the hypothesis that the population means are the same. An equal variance check was used to determine the type of t-test. A confidence level of 95 % (a p-value of less than 0.05)

was considered to be significant. The statistical procedure was then repeated controlling for subject weight.

RESULTS AND DISCUSSION

A database was created containing measurements for the male and female vertebral geometry parameters at each vertebral level C3 through C7. Significant differences were found between the male and female parameters at all of the cervical levels (Table 1). The parameters were divided into five groups by the region they define: articular process (ap), pedicle (pd), spinous process (sp), transverse process (tp), and vertebral body (vb). Significant differences were found between the genders in each of these regions. A majority of the differences remained after controlling for subject weight (77 of 175 measurements), including vertebral width and height, which is in agreement with the literature.

CONCLUSIONS

This study shows that the female cervical spine is significantly different from the male cervical spine; the female cervical spine is not simply a scaled version of the male cervical spine. Significant geometrical differences occur between the genders at each of the vertebral levels from C3 to C7. The geometry parameters found in this study are currently being used to generate parametric FE models of both genders.

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Table 1: Measured Parameters by Vertebral Level (shaded cells, female v. male $p < 0.05$).

C3	C4	C5	C6	C7
ap1	ap1	ap1	ap1	ap1
ap2	ap2	ap2	ap2	ap2
ap3	ap3	ap3	ap3	ap3
ap4	ap4	ap4	ap4	ap4
ap5	ap5	ap5	ap5	ap5
ap6	ap6	ap6	ap6	ap6
ap7	ap7	ap7	ap7	ap7
ap8	ap8	ap8	ap8	ap8
pd1	pd1	pd1	pd1	pd1
sp1	sp1	sp1	sp1	sp1
sp2	sp2	sp2	sp2	sp2
sp3	sp3	sp3	sp3	sp3
sp4	sp4	sp4	sp4	sp4
sp5	sp5	sp5	sp5	sp5
sp6	sp6	sp6	sp6	sp6
sp7	sp7	sp7	sp7	sp7
tp1	tp1	tp1	tp1	tp1
tp2	tp2	tp2	tp2	tp2
tp3	tp3	tp3	tp3	tp3
vb1	vb1	vb1	vb1	vb1
vb2	vb2	vb2	vb2	vb2
vb3	vb3	vb3	vb3	vb3
vb4	vb4	vb4	vb4	vb4
vb5	vb5	vb5	vb5	vb5
vb6	vb6	vb6	vb6	vb6
vb7	vb7	vb7	vb7	vb7
vb8	vb8	vb8	vb8	vb8
vb9	vb9	vb9	vb9	vb9
vb10	vb10	vb10	vb10	vb10
vb11	vb11	vb11	vb11	vb11
vb12	vb12	vb12	vb12	vb12
vb13	vb13	vb13	vb13	vb13
vb14	vb14	vb14	vb14	vb14
vb15	vb15	vb15	vb15	vb15
vb16	vb16	vb16	vb16	vb16

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