Cervical Spine Bone Mineral Density as a Function of Vertebral Level and Anatomic Location

Thorhauer, E; Anderst, W; Donaldson, W; Lee, J; Kang, J
Department of Orthopaedic Surgery, University of Pittsburgh, Pittsburgh, PA
anderst@pitt.edu

Introduction
Bone mineral density (BMD) measurements acquired from quantitative computed tomography (QCT) scans have been shown to correlate with bone mechanical properties such as strength, stiffness and yield load\textsuperscript{1,4}. Information on the variation in cervical spine BMD with anatomic location and vertebral level does not currently exist. This information would be beneficial to surgeons who must secure instrumentation to the vertebrae during surgery and to basic scientists who assign mechanical properties of bones in finite element models of the spine.

The objectives of this study were first, to determine the overall BMD of cervical vertebrae C3-C7, and second, to determine the BMD in specific anatomic regions within C3-C7. The null hypotheses tested were first, that BMD does not change with vertebral level, and second, that BMD is not different across anatomical regions.

Methods
High resolution CT scans (0.29x0.29x1.25 mm voxels) of the subaxial cervical spine (C3-C7) were collected from 17 subjects in this IRB-approved study. Eight were cervical radiculopathy patients (age 46.6±7.5 yrs; 5F, 3M) and nine were asymptomatic (age 46.6±6.6 yrs; 4F, 5M). All CT scans were performed on the same scanner (GE LightSpeed 16) using identical CT protocol parameters. CT pixel values were converted from Hounsfield units into Bone mineral density (BMD) values using a calibration phantom (CRS, Model 62, Electron Density Phantom). Bone tissue was segmented from the CT volume using commercial software (Mimics software, Materialise, Inc.) to generate a three-dimensional (3D) model of each vertebra. Eleven anatomic regions of interest were identified within each 3D bone model (Fig. 1). Additional regions of interest were defined on the superior and inferior endplates of the central vertebral body (approximately 3 mm in thickness). Custom software calculated the average BMD within each region of interest. Repeated measures analysis of variance, with the Sidak adjustment for multiple comparisons, was used to test for differences within subjects by level (C3-C7) and anatomic location with α = 0.05.

Results
Average BMD by level was 469, 497, 502, 472 and 414 mg/cc for C3 through C7, respectively (Fig. 2). BMD typically peaked at C5 and progressively decreased toward C3 and C7 through most anatomic locations, with the notable exception being the spinous process, where BMD was largest in C6 and C7 (Fig. 4). Superior and inferior endplate BMD (superior: 377, 391, 394, 295 mg/cc, and inferior: 396, 388, 394, 380, 331 mg/cc for C3-C7, respectively), was not significantly different at any level, but was significantly lower at C7 in comparison to all other levels (all p < 0.002).

Discussion
The age of the subjects in this study was representative of patients who typically receive treatment for cervical spine disorders. Results were consistent with previous reports that used single CT slices and showed cervical vertebral body\textsuperscript{14} and cortical shell\textsuperscript{1} BMD highest at C5 and decreasing in the direction of C3 and C7. The relatively low BMD throughout C7, including the endplates, indicates optimal surgical treatment of this level may be different than for C3-C6 (e.g. screw modification, disc replacement design, the need to fuse additional levels).

This study revealed for the first time the significant variation in BMD according to anatomical location. The significant difference between pedicle and lateral mass BMD corresponds well to a previous study that found cervical pedicle screws have a significantly higher resistance to pull-out forces than lateral mass screws\textsuperscript{6}. The large difference in BMD between the pedicles and lateral masses on one hand and the central vertebral body on the other hand, imply significant differences in the mechanical properties of these anatomic regions. This implication agrees with clinical experience that shows posterior fusion results in a more solid construct following surgery than anterior fusion.

The wide variation in BMD across different anatomical locations suggest substantial differences exist in regional bone mechanical properties, as it has been shown that a 25% decrease in bone tissue results in a more than 50% decrease in strength of the vertebral body\textsuperscript{5}. It may be necessary to take the variation in BMD across anatomical regions into account when assigning mechanical properties to the vertebrae in modeling applications.


Acknowledgement: Funded by NIH/NIAMS, Grant R03-AR056265 and the Cervical Spine Research Society 21st Century Development Grant.