Selective Densitometry of the Lumbar Spine

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Introduction: Bone mineral density (BMD) has been identified as a major factor in spine construct strength, with failures resulting in pedicle screw loosening and pullout [2,3]. Computed tomography (CT) scans have been shown to effectively measure BMD [1,4]. Previous research has utilized this linear correlation of CT Hounsfield Units (HU) to BMD in order to determine BMD as a function of anatomic location within cervical vertebrae [1]; however, the lumbar spine has not yet been reported on. The goal of this study was to describe BMD of anatomical regions within lumbar vertebrae using the correlation between HU and BMD. It was hypothesized that posterior elements of the lumbar vertebrae would exhibit significantly different BMD than the vertebral body. This was tested through means comparison of BMD for each anatomical region

Methods: Three-dimensional models of the lumbar spine (L1 - L5) were generated by high-resolution helical CT scans of three fresh-frozen cadaver specimens. The lumbar spine was digitally isolated from surrounding tissue by applying a preset thresholding filter for adult bone to the CT scans using medical image processing software. Using this thresholding as well as manual segmentation, the spine model was separated into five vertebrae, followed by segmentation of each vertebra into seven anatomic regions and determination of average HU (Figure 1). HU was then converted to BMD with calibration phantoms of known BMD. One-way ANOVA indicated any significant differences in BMD of the vertebral regions.

Results: Overall mean BMD in vertebral regions ranged from 172-393 mg/cm^3, with the highest and lowest BMD found in the lamina and vertebral body, respectively (Figure 2). Vertebral regions demonstrated BMD values in three distinct groups (Figure 2, p < 0.03). The vertebral body and transverse processes represent one group, with significantly lower BMD (146 ± 27, 172 ± 62 mg/cm^3) than other regions. The spinous process, pedicles, and superior articular processes represent a second group, with moderate BMD (281 ± 74, 303 ± 77, 304 ± 79 mg/cm^3). Finally, the inferior articular process and lamina represent a third group, with significantly higher BMD (390 ± 98, 393 ± 116 mg/cm^3) than any other region.

Discussion: This study determined relative BMD of clinically relevant anatomic regions of the lumbar vertebra. The lamina and inferior articular processes exhibited the highest BMD, while the BMD of the pedicles was significantly lower (p < 0.02). Standard lumbar fusion currently uses the vertebral body and pedicles as primary locations for osseous fixation, i.e. pedicle screws. We have demonstrated that these anatomic regions have a relatively low BMD. Thus, utilization of the posterior elements of the lumbar spine - especially the lamina and inferior articular processes - may be advantageous either as a supplement to modern constructs or the primary site for fixation in posterior spinal fusion, possibly mitigating spinal construct failures due to pedicle screw loosening or pull-out. The vertebral body and transverse process demonstrated significantly lower BMD than all other anatomic regions (p < 0.00003). This finding was expected since the vertebral body is comprised mostly of cancellous bone and vascular cavities. However, this result also suggests that the standard procedure of determining spine BMD by DEXA (dual-energy X-ray absorptiometry) scans of the vertebral body may be limited. We observed a statistically significant difference between the region evaluated for bone quality (vertebral body) and the region utilized for posterior fixation (pedicle). Poor vertebral body bone quality may correspond to decreased pedicle bone quality; however, our results indicate a possible need to evaluate specific anatomical regions when bone quality is in question. As such, CT may be more valuable than DEXA when assessing BMD of specific anatomic regions prior to lumbar spinal fusion. This may be particularly useful in patients with existing poor bone quality. Future research from our group will focus on understanding the relationship between BMD and vertebral region across demographic groups. We observed interesting results for lumbar vertebrae in comparison to a previously published report of cervical densitometry by Anderst et al. In both cervical and lumbar vertebrae, statistically distinct groups of regions with similar BMD were discernible. Additionally, the vertebral body BMD in both the cervical and lumbar spine was significantly lower than most remaining vertebral regions and lowest overall. The main dissimilarity was the relative BMD ranking; highest BMD was exhibited in the pedicles for the cervical spine as opposed to the lamina for the lumbar spine. Mean BMD range for lumbar spine (172-393 mg/cm^3) was also lower than that reported for cervical spine (290-630 mg/cm^3). Several limitations were encountered during this study. Imaging calibration employed two bone phantoms. Additional phantoms could have been included, but linearity of the BMD and HU correlation was assumed based on prior research [4]. Sample size was also limited, but still yielded results with statistical significance. An increased sample size would allow grouping of demographics such as age, sex, and bone condition (i.e., level of osteoporosis). Pending work by our group is underway to determine if trends observed in this study are consistent in osteoporotic spines specifically, given the elevated concern for construct failure.

Significance: This study was able to determine relative BMD of clinically relevant anatomic regions of the lumbar vertebra.
Resulting data indicate that utilization of the posterior elements of the lumbar spine - especially the lamina and inferior articular processes - may be advantageous for hardware fixation.

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**References:**
Figure 1: Segmented vertebra with labeled regions.
Figure 2: Mean BMD of each vertebral region with different shapes representing significant differences in BMD.

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