Population-Based Local Multi-Parametric Comparisons of HR-pQCT Studies

Julio Carballido-Gamio[1]
Serena Bonaretti[1]
Galateia J. Kazakia[1]
Sundeep Khosla[2]
Thomas F. Lang[1]
Andrew J. Burghardt[1]

[1] Department of Radiology and Biomedical Imaging
University of California, San Francisco, San Francisco, CA, USA
[2] Division of Endocrinology, Diabetes, Metabolism and Nutrition
Department of Internal Medicine, College of Medicine
Mayo Clinic, Rochester, MN, USA

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Abstract: 400 words maximum.

Introduction

Conventional HR-pQCT quantification approaches average bone features over large regions and ignore their spatial association within the structure, obscuring local information regarding their distribution and how they contribute to bone strength. Here, we present 3D image analysis techniques for population-scale multi-parametric spatial comparisons of bone quality features. Specifically, we present: 1) voxel-based morphometry (VBM), and 2) a surface-based framework to encode cortical bone features in a laminar-wise manner, which is then used to measure cortical bone thickness and perform statistical parametric mapping (SPM).

Methods

Imaging

Scan-rescan HR-pQCT acquisitions with repositioning of the distal radius and tibia were acquired in 30 subjects.

VBM

The radius and tibia of one subject were selected as references. Bone feature maps of the remaining subjects were homogenized and spatially normalized to the references based on affine and nonlinear registrations. Voxel-wise multi-parametric comparisons (vBMD and BV/TV) were then performed between "follow-up" and "baseline" scans, using Hotelling's T2 tests for dependent samples and false discovery rate correction (FDR).

Surface-Based Cortical Bone Analysis

Bone segmentations, vBMD maps, non-local means, and fuzzy logic were used to generate soft cortical bone segmentations: [0=marrow, 1=bone]. A one-to-one matching between the periosteal surface and the endosteal boundary was established through streamlines computed with the Laplace's equation, thus enabling a laminar analysis.

-Streamline Integral Thickness (SIT)

Integrals of the soft segmentation along the streamlines yielded a porosity-weighted cortical bone thickness measure. The streamline lengths provided an apparent measure of cortical thickness.

-SPM

VBM registrations were used to spatially normalize the periosteal surfaces. Analogous to VBM, multi-parametric vertex-wise comparisons of SIT and mean streamline vBMD were performed.

-Global Reproducibility

Rigid matching of individual "follow-up" and "baseline" surfaces was performed to assess global reproducibility of thickness and mean streamline vBMD using CV_{RMS} (absolute errors).

Results

Figure-1 shows a spatial normalization example and a mean BV/TV map. Cortical thickness maps of a scan-rescan example, mean cortical thickness maps, and a laminar vBMD example are shown in Figure-2. No significantly different voxels or vertices were found after FDR correction, indicating no significant multi-parametric differences between "baseline" and "follow-up" scans. Global reproducibility yielded CV_{RMS} of 1.6% (0.018mm) and 0.9% (0.013mm) for apparent thickness, 1.5% (0.014mm) and 0.9% (0.010mm) for SIT, and 1.2% (4.68mg/cm^3) and 0.8% (3.05mg/cm^3) for vBMD, for the radius and tibia, respectively.

Conclusions

Advanced 3D image analysis techniques may be employed for population-based local multi-parametric comparisons of HR-pQCT studies with high reproducibility.

Acknowledgments

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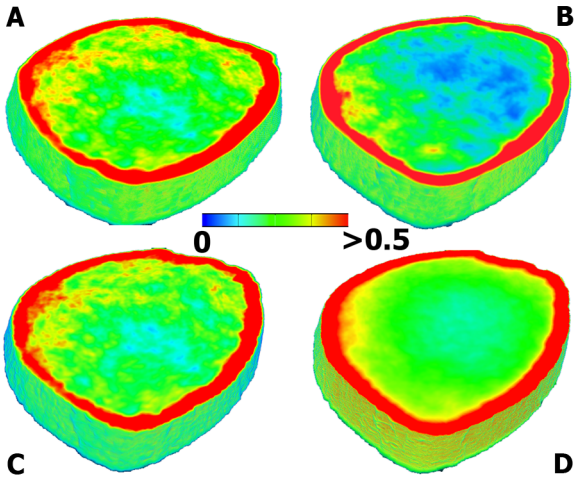

Figure 1. Cross-sections of voxel-wise analyses: A) Representative homogenized BV/TV map. B) Reference shape. C) Map in A after spatial normalization to B. D) Mean "baseline" BV/TV map.

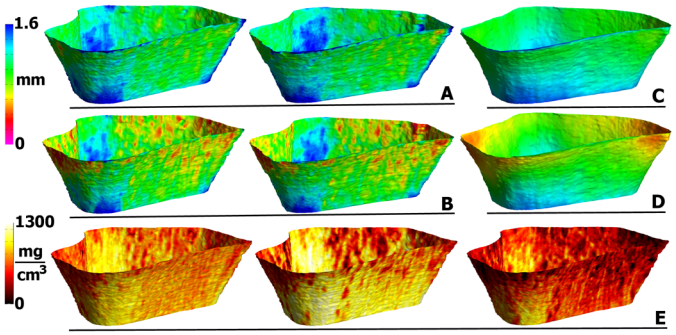

Figure 2. Surface-based analysis: A) Representative "baseline" and "follow-up" apparent cortical bone thickness maps. B) Representative "baseline" and "follow-up" SIT maps. C) Mean apparent cortical bone thickness map. D) Mean SIT map. E) Representative laminar vBMD maps: periosteal layer, middle layer, and endosteal layer.