Geodesic Topological Analysis of Trabecular Bone Micro-Architecture of High-Spatial Resolution Magnetic Resonance Images

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Introduction

The quantification of the complex trabecular bone network in the study of osteoporosis is certainly an important component of trabecular bone quality assessment. MRI and more recently high-resolution peripheral quantitative computed tomography (HR-pQCT) are currently the main imaging modalities for the in vivo study of trabecular bone micro-architecture. Common computed trabecular bone parameters include apparent bone volume to tissue volume (BVTV), apparent trabecular bone number (app.Tb.N.), spacing (app.Tb.Sp.), and thickness (app.Tb.Th.), as well as anisotropy, and connectivity in terms of the Euler number [1]. Digital topological analysis (DTA), where each voxel is classified into different categories based on its local topology, is also becoming an important tool for the assessment of bone integrity from medical images with high-spatial resolution [2]. In this work a new trabecular bone analysis quantification technique is presented under the name of *G*eodesic *T*opological *A*nalysis or GTA. New apparent trabecular bone parameters derived from GTA are also presented under the names of apparent trabecular bone volume distribution (app.Tb.V.D.) , apparent trabecular bone junction space (app.Tb.J.Sp.), and apparent trabecular bone distance to junction (app.Tb.D.J).

Materials and Methods

Calcaneal and vertebral specimens were obtained from 30 formalin-fixed human cadaver (15 male; 15 female; mean age = 82 ± 9 years; Institute of Anatomy at the Ludwig Maximilians University, Munich, Germany). Sagittal high-spatial resolution MR images of the calcanei were obtained at 3.0 T (Signa; GE Medical Systems, Milwaukee, WI) with a two-element phased-array wrist coil using a 3D fast gradient recalled echo (FGRE) sequence with TR/TE of 18.5/4.3 ms, 20° flip angle, 12.5 kHz BW, FOV of 8 cm, 0.5 mm slice thickness, and a matrix size of 512x384 for a final in-plane resolution of 156 µm x 156 µm in 7min and 34 s. Radiographs of the entire thoracic and lumbar spines from the same human specimens were obtained for the assessment of vertebral fractures. Circular regions of interest (ROI) including trabecular bone and marrow, and avoiding cortical bone and air artifacts were placed in the posterior part of the calcanei (Fig. 1a) . Trabecular bone in the ROI was segmented by applying hard fuzzy c-means (FCM) clustering yielding a binary image as is shown in Fig. 1b. The skeleton of the binary images was calculated and their junctions identified (Fig. 1c). By using geodesic distances each bone pixel in the binary image was then assigned to its closest junction as is represented in Fig. 1d with color encoding. The app.Tb.V.D. represents the bone volume assigned to each junction (mm^3), while the app.Tb.J.Sp. represents the geodesic distance between closest junctions (mm), and the app.Tb.D.J. represents the largest geodesic distance between the junction an its set of assigned pixels (mm).

The performance of the GTA derived parameters was evaluated in terms of its ability to discriminate between subjects with and without vertebral fractures as derived from radiographs of the thoracic and lumbar spine. For this purpose receiver-operator characteristic (ROC) analysis with area under de curve (AUC) values was performed.

Results

The performance of the proposed GTA parameters in terms of vertebral fracture discrimination is shown in Fig. 2 and quantitatively summarized in Table I. The p value for the standard deviation (std) of the app.Tb.V.D. was $p<0.058$.

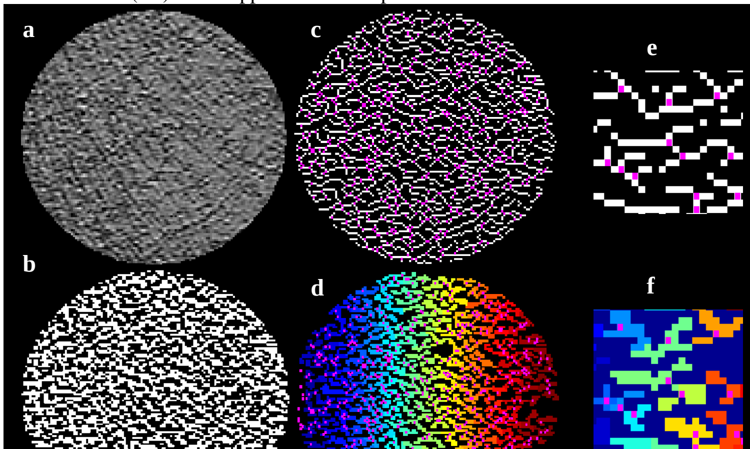

Fig. 1. a) Calcaneal MRI region of interest. b) Binarized region of interest. c) Skeletonized region of interest with pixel junctions represented in magenta. d) Color coded map of pixel assignment to closest junction (blue=junction #0; red = junction #640; magenta = junction). e) Zoom of a section in c). f) Zoom of a section in d) with different window level (blue=junction #235; red = junction #405).

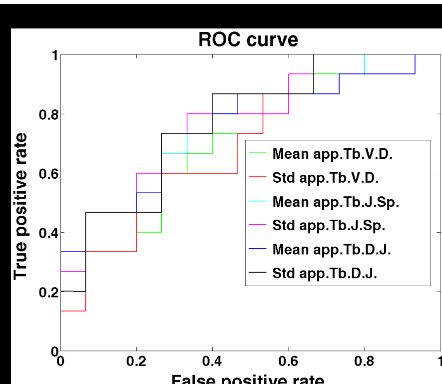

Fig. 2. ROCs for GTA parameters.

Table I. AUC for ROC analysis.

GTA parameter	AUC
Mean app.Tb.V.D.	0.702*
Std app.Tb.V.D.	0.706
Mean app.Tb.J.Sp.	0.751*
Std app.Tb.J.Sp.	0.777*
Mean app.Tb.D.J.	0.755*
Std app.Tb.D.J	0.768*

* p<0.05

Discussion

In this work we have presented *G*eodesic *T*opological *A*nalysis and its derived parameters as an alternative technique to quantify the trabecular bone micro-architecture of high-spatial resolution MR images. Although the technique has been presented in 2D, it is currently fully functional in 3D. The individual AUCs of the ROCs for the new parameters showed moderate vertebral fracture discrimination. The mean values of all the proposed parameters were higher for the subjects with fracture than for those without fracture. A possible explanation of this phenomenon could be that as the geodesic distances between the junctions increase, the amount of bone that the junctions have to support also increases, as well as the geodesic distances of the bone elements to the junctions, making the bones more susceptible to fracture. Current work is focused on data mining techniques and comparison of the proposed parameters to those already established in the field such as BVTV, app.Tb.N., app.Tb.Sp., app.Tb.Th., as well as DTA parameters. The application of the proposed methodology to images of HR-pQCT is also in progress, as well as further analysis of the presented specimens with additional available variables such as calcaneal and proximal femur BMD (g/cm2), spinal BMD (g/ml), and mechanical testing of the proximal femur.

References

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