CT-Based Characterization of Transverse and Longitudinal Trabeculae and Its Applications

Nov 05, 2020

Xiaoliu Zhang\textsuperscript{1}, Elena M Letuchy\textsuperscript{2}, Steven M Levy\textsuperscript{3}, James C Torner\textsuperscript{4}, Punam K Saha\textsuperscript{1}

\textsuperscript{1}Department of Electrical and Computer Engineering, University of Iowa, USA
\textsuperscript{2}College of Public Health, University of Iowa, USA
\textsuperscript{3}Department of Preventive and Community Dentistry, University of Iowa, USA
\textsuperscript{4}Department of Epidemiology, University of Iowa, USA
Transverse / Longitudinal Trabeculae

- Trabeculae consist of transverse and longitudinal structures
- Transverse trabeculae are critical in arresting buckling and compressive fracture of longitudinal trabeculae
- This research requires
  - Segmentation of individual trabeculae
  - Orientation computation of individual trabeculae
- Challenges
  - Trabecular bone is a complex 3-D network
  - Wide variability for digital junctions
  - Long and curved trabecular segments
Workflow

CT Images → Bone Volume Fraction (BVF) Computation and Cavity Filling → Curve Skeletonization and Pruning

Splitting Curves into Relatively Linear Segments → Ungluing Curve Segments at Junctions → Junction Detection

Trabecular Orientation Computation → Characterization of Transverse and Longitudinal Trabeculae
Curve segments

• Detect curve junctions
• Unglue at curve junctions
  – Long and curved trabecular segments are often present
• Splitting such trabeculae is needed for accurate computation of orientation
  – Fit a B-Spline and find the farthest point

3D volume  Individual trabecular curves  Individual trabecular segmentation
Trabecular Orientation Computation

- Fit a B-spline to individual trabecular curve segments
- Generate uniform sample points on the B-spline representation of each trabecular curve
- Apply principle component analysis on sample points and determine the principle orientation
- Propagate orientation from curve skeleton voxels to trabecular volume using a nearest skeletal voxel method
Experiments and Data Description

• Experimental Goals
  – To examine repeat CT scan reproducibility
  – To study relationships between trabecular transverse / longitudinal measures with sex and body size in a human study

• Cadaveric ankle specimens
  – 12 fresh-frozen cadaveric ankle specimens
  – Repeat CT scans were performed on these specimens with repositioning the specimens on the scanner table before each repeat scan

• Human subjects
  – Healthy young adults from the Iowa Bone Development Study (N = 99; 49 females; age: 19.4± 0.4 years)
  – High-resolution angle CT scan on a Siemens SOMATOM Definition Flash scanner
  – Height: Female (167.2±6.7 cm), Male (179.4±8.2 cm)
  – Weight: Female (69.3±18.6 kg), Male (85.4±16.6 kg)
Reproducibility Analysis of Trabecular Measures

- Applied to cadaveric ankle specimens (n = 12)
  - Values of trabecular measures were computed over small spherical ROIs of diameter 7 mm
  - Randomly select 15 ROIs over 30% peel at 4 to 8% of tibia
  - A total of 15 × 12 = 180 ROIs
  - For each measure, the ICC of repeat scan values over matching ROIs were computed

<table>
<thead>
<tr>
<th>Variables</th>
<th>Reproducibility (ICC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tb.vBMD</td>
<td>0.999</td>
</tr>
<tr>
<td>Tb.tBMD</td>
<td>0.983</td>
</tr>
<tr>
<td>Tb.IBMD</td>
<td>0.947</td>
</tr>
</tbody>
</table>
Human Study Data and Analysis

• Summary values for different trabecular measures were derived from inner and outer ROIs at 4-6% tibial section

• Inner region: 60% peeled region

• Outer region: the annular region between 30 and 60% peeling

• Data Analysis
  – Correlation analysis to investigate relationships of trabecular measures with body size – height, weight, and BMI
  – T-test for group comparison for sex differences in Tb measures
## Relationships Trabecular Measures with Body Size

<table>
<thead>
<tr>
<th>Variables</th>
<th>Inner ROI</th>
<th>Outer ROI</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Tb.vBMD</td>
<td>Tb.tBMD</td>
</tr>
<tr>
<td></td>
<td>Tb.vBMD</td>
<td>Tb.tBMD</td>
</tr>
<tr>
<td>Females (N=49)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Height (cm)</td>
<td>0.36</td>
<td>0.36</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>0.48</td>
<td>0.46</td>
</tr>
<tr>
<td>BMI</td>
<td>0.41</td>
<td>0.39</td>
</tr>
<tr>
<td>Males (N=50)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Height (cm)</td>
<td>-0.01</td>
<td>-0.01</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>0.34</td>
<td>0.31</td>
</tr>
<tr>
<td>BMI</td>
<td>0.37</td>
<td>0.33</td>
</tr>
</tbody>
</table>
## Gender Distributions of Trabecular Measures

<table>
<thead>
<tr>
<th>Variables</th>
<th>Males (N=50)</th>
<th>Females (N=49)</th>
<th>Mean sex diff (SE) (Male = ref)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean (SD)</td>
<td>Median (Range)</td>
<td>Mean (SD)</td>
</tr>
<tr>
<td>Inner ROI</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tb.vBMD</td>
<td>1146 (33)</td>
<td>1148 (1079, 1212)</td>
<td>1132 (31)</td>
</tr>
<tr>
<td>Tb.tBMD</td>
<td>452 (105)</td>
<td>465 (217, 652)</td>
<td>402 (116)</td>
</tr>
<tr>
<td>Tb.lBMD</td>
<td>349 (59)</td>
<td>349 (193, 510)</td>
<td>320 (65)</td>
</tr>
<tr>
<td>Outer ROI</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tb.vBMD</td>
<td>1204 (31)</td>
<td>1203 (1148, 1280)</td>
<td>1176 (32)</td>
</tr>
<tr>
<td>Tb.tBMD</td>
<td>496 (111)</td>
<td>497 (217, 767)</td>
<td>385 (121)</td>
</tr>
<tr>
<td>Tb.lBMD</td>
<td>373 (68)</td>
<td>375 (190, 558)</td>
<td>303 (73)</td>
</tr>
</tbody>
</table>

*p-values < 0.05, **-p-values < 0.01
Conclusions

• A new *in vivo* CT-based method has been presented for characterizing transverse and longitudinal trabeculae
  – Novel characterization of digital junctions
  – New methods for individual trabecular segmentation

• Trabecular transverse / longitudinal measures are reproducible

• Trabecular transverse / longitudinal measures have higher correlation with weight than height

• Trabecular measures in females show stronger correlation with body size than males

• Female sex is associated with fewer transverse / longitudinal trabeculae
Acknowledgement

• This work was supported by the NIH grant R01 HL142042