VALIDATION OF µCT-GENERATED CARPAL BONE CARTILAGE THICKNESS MAPS

* Casey, JC; **Moore, DC; *Crisco, JJ
+Department of Orthopaedics, Brown Medical School/Rhode Island Hospital, Providence, RI, USA
douglas_moore@brown.edu

INTRODUCTION

Understanding cartilage contact is critical to understanding the normal bony articulations in the wrist, as well as the consequences of conformational changes that develop after wrist injury (e.g. scapholunate advanced collapse, or SLAC wrist).

We have recently initiated a research program aimed at developing patient-specific kinematic models of the wrist. Our kinematic data is generated via markerless registration of the bones from serial CT scans of the wrist at various positions of flexion, extension, radial and ulnar deviation (pure and combined) [1]. An important part of our model will be the inclusion of cartilage on the CT-generated bone surfaces.

We recently reported the feasibility of using micro-computed tomography (µCT) to generate 3-D thickness maps for the carpal bones [2]. This study was performed to validate this technique and provide estimates of associated error.

METHODS

µCT-generated cartilage thickness measurements were validated via direct comparison to 2-D plane section images generated using a high-resolution flatbed scanner (in a preliminary study, flatbed scan images of a high-precision composite polycarbonate/polyvinylchloride disk were found to be within 30 µm of those measured with a digital micrometer). Specimens and Sectioning The lunate (Lun), scaphoid (Sca), trapezoid (Tzd), and two triquetrum (Tqm) were dissected from two unembalmed cadavers (both female, ages 58 and 69). The bones were then sectioned in the frontal plane with a low speed diamond saw, yielding thin (~ 0.27 mm) sections for scanning. The planar cut surface was used to register the “z-coordinate” of the flatbed and µCT images.

Flatbed Image Acquisition Full color 4800 dpi (~5.3 µm/pixel) transmitted light scans of the bone slices were obtained using a high-resolution flatbed scanner (UMAX, 2100XL, Dallas, TX). The images were converted to grayscale, inverted, and thresholded using Analyze image analysis software (BIR, Rochester, MN). The inner (bone) and outer (cartilage) surfaces were delineated using Analyze’s spline function and exported as a series of points.

µCT Image Acquisition The cut bone sections were mounted on a specially-designed stage and scanned in dilute iodine-based contrast (Omnipaque, Amersham Health., Princeton, NJ) with a µCT 40 (Scanco Medical, Bassersdorf, Switzerland) such that the individual CT slice images were parallel to the cut bone surfaces. The image file was thresholded and a single representative high-resolution slice image was exported as a TIFF file. As with the flatbed image, Analyze image analysis software was used to generate point clouds for the inner and outer cartilage surfaces.

Cartilage Thickness Comparison The flatbed and µCT generated point clouds were imported into Geomagic (Geomagic, Raindrop, Durham, NC), registered to one another, and the geometric center was calculated. Regions of the contours clearly identified as articular cartilage (as opposed to ligament insertion sites) were then selected for thickness quantification. The radial distances to the inner (ID) and outer cartilage (OD) surfaces were calculated at one degree intervals using code custom written in Matlab (Mathworks, Natick, MA); cartilage thickness was calculated as OD-ID. The absolute difference in cartilage thickness calculated from the flatbed and µCT images (Delta) was compared for each bone using paired t-tests.

RESULTS

Subjectively, the contours obtained from the µCT images aligned very closely with those from the flatbed image. The radial thickness values calculated from the image pairs generally agreed very well; even where the two techniques did yield significant differences in cartilage thickness (Tqm2 and Sca), the differences were only on the order of 50µm (Table 1).

<table>
<thead>
<tr>
<th>Bone</th>
<th>Flatbed (mm)</th>
<th>µCT (mm)</th>
<th>**(Flat-µCT) (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tzd</td>
<td>0.656 ± 0.148</td>
<td>0.658 ± 0.163</td>
<td>0.002 ± 0.025</td>
</tr>
<tr>
<td>Tqm2</td>
<td>0.861 ± 0.235</td>
<td>0.865 ± 0.203</td>
<td>0.004 ± 0.023</td>
</tr>
<tr>
<td>Lun</td>
<td>0.681 ± 0.168</td>
<td>0.712 ± 0.175</td>
<td>0.031 ± 0.049</td>
</tr>
<tr>
<td>Sca</td>
<td>0.861 ± 0.235</td>
<td>0.865 ± 0.203</td>
<td>0.004 ± 0.023</td>
</tr>
</tbody>
</table>

**n = # of points and degrees of cartilage coverage for each bone slice
** Average of absolute difference (Delta) at each degree interval
† Significantly different

DISCUSSION

This study was performed to validate the use of µCT to generate thickness maps of the carpal bones. To do so, 2-D µCT-generated thickness maps were compared to high-resolution images acquired via direct flatbed scanning. Our results confirm that the µCT scanned images were accurate, with absolute cartilage thickness errors generally on the order of 5% (within 40-50 µm). In fact, the method we used (calculating thickness along a radius) probably overestimated absolute cartilage thickness errors slightly. Nevertheless, the results of this study give us confidence that we can generate accurate 3-D cartilage thickness maps using µCT.

REFERENCES

1) Crisco et al. J Orthopaedic Research, 1999

ACKNOWLEDGEMENTS RIH Orthopaedic Foundation, Inc., NIH grant HD052127, and University Orthopedics Inc. funded this work. Jason Machan Ph.D. provided assistance with statistical analysis.

53rd Annual Meeting of the Orthopaedic Research Society
Poster No: 1185