Bone loading estimation in the human distal radius

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Introduction

High-resolution imaging techniques allow the assessment of bone micro-architecture at the distal radius in patients. In combination with FE analysis, this technique now enables an accurate diagnosis of bone strength1. A further prognosis of bone strength would be possible by using bone remodelling simulations able to predict changes in the micro-architecture due to, e.g. osteoporosis, changes in activity, or treatment strategies. To run such simulations, however, patient-specific loading conditions are needed since these vary considerably between patients. We previously developed a method2 to estimate these loading conditions from images of bone architecture. However, because clinical measurements represent only a small region of the radius, it is unclear if this method would produce realistic results.

The aim of this study was therefore to test if the load estimation algorithm applied to this clinically measured section would predict forces as measured experimentally.

Method

HR-pQCT images of distal human cadaveric forearms (n=9) from another study3 were used (Fig. 1a). A sub-volume of interest corresponding to the region measured clinically (Fig. 1b) was used for the load estimation. Using these force predictions, the forces that act at the carpal bones (S and L, Fig. 1a) were calculated by requiring force and moment equilibrium of the distal end of the bone. The forces determined at these bones were then compared to experimental measurements.

Results

<table>
<thead>
<tr>
<th>Bone</th>
<th>Calculated force average</th>
<th>Calculated force range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scaphoid</td>
<td>72 N</td>
<td>28 – 179 N</td>
</tr>
<tr>
<td>Lunate</td>
<td>45 N</td>
<td>18 – 86 N</td>
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</tbody>
</table>

Discussion

The bone loading estimation method was able to predict loads that resulted in realistic carpal bone forces. Especially the force transmission ratio between scaphoid and lunate was in close agreement with results from cadaver studies4,5 but also the force magnitudes6. The force magnitudes varied in a wide but realistic range. This large variation could be explained by large differences in bone morphology between subjects, as illustrated by comparing two extreme cases (Fig. 2).

The study thus shows that subject-specific determination of bone loading based on bone morphology is possible and necessary. We expect that this approach offers new opportunities for patient-specific simulations of load-adaptive bone remodeling. Such tools could ultimately help clinicians to improve their diagnosis.

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References