Radiocarpal Joint Kinetics During Initial Wrist Positions: An Experimental And Computational Study.

Eike Jakubowitz¹, Balász Kaszap², Hui Zhang¹, Andreas Kellotat⁴, Matthias Bode¹, Martin Mack¹, Wolfgang Daecke³.
¹Justus-Liebig-University of Giessen, Giessen, Germany, ²University of Heidelberg, Heidelberg, Germany, ³University of Frankfurt, Frankfurt, Germany.


Introduction: Compared to hip and knee joint arthroplasty the replacement of the radiocarpal joint has not yet been established as a standard treatment. Premature loosening of components seems to be a main complication [1]. As a result, further developments of implants could not be observed in the last few years, in particular with regard to the lack of data concerning radiocarpal joint kinetics. Apart from a few studies focusing on compressive joint stresses the acting joint forces remain still unclear. Limitations for an experimental examination of these joint forces can be addressed to small bones and therefore little space to place any force transducers.

In the present study we determine (1) the radiocarpal contact forces and (2) correspondent contact points on distal radius cartilage, both as a function of initial wrist positions.

Methods: Wrists of 5 intact arms disarticulated at left shoulder joint were brought standardized into neutral, extension, flexion, ulnar- and radial-deviation positions. In order to balance hands 3 times in each defined position, synergetic tension was applied into tendons of main forearm muscles (Mm. extensor carpi ulnaris, extensor carpi radialis longus, extensor carpi radialis brevis, flexor carpi ulnaris, flexor carpi radialis and abductor pollicis longus) by a simulator constructed suitable for CT. At the same time an indirect force measurement was carried out by a strain gauge sensor with multiple degrees of freedom (MC1A-6-500, AMTI, USA) replacing a distal radius segment close to the joint.

In order to count back force vectors into the radiocarpal joint coordinates of chondral contact points between Os Lunatum and distal radius, as well as between Os Scaphoideum and radius had to be detected for each repetition of wrist position. Nevertheless, specimens could only be CT-scanned due to multiple metal parts being existent during force measurements. Therefore, we built bone-cartilage models out of CT- and MRI-datasets generated from position fixed specimens before the force measurements.

In order to reach position fixed bones we thawed specimens gradually in a modified blood bank refrigerator (Type BR750G, Dometic GmbH, Siegen, Germany) to 30.2 ± 0.2°F. This temperature provided an intermediate aggregation of water molecules resulting in sufficient electron mobility for MRI signaling, whereas specimens remained still fixed [2].

Both datasets were segmented and registered with Amira® (FEI Visualization Sciences Group, USA) and Geomagic Studio® (Geomaginc Inc., USA). Displacements and resulting contact points of cartilage structures could be determined computational subsequent to the investigation by repeated registrations of single hand bones with already overlaid cartilages into CT-datasets from force measurements (Figure 1). Resulting forces were normalized with respect to forearm volumes calculated out of MRI-datasets.

The Mann-Whitney U test was deployed for the resultant and single force values to find potential differences between the driven wrist positions.

Results: Flexion led to a significant increase of radiocarpal joint contact forces for both Scaphoideum and Lunatum with respect to neutral position. In contrast extension caused a significant decrease compared to flexion. Compared to neutral extension caused just a significant decrease of Lunatum contact forces. The highest force transmission of 125.4N (18.2%BW) was detected during flexion; followed by radial-deviation (111.6; 16.2%BW), neutral (111.4; 16.2%BW), extension (109.5N; 15.9%BW) and ulnar-deviation (103.5N; 15.0%BW).

The main differences between wrist positions were found regarding changes of forces between both carpal bones (Table 1). Forces onto Radius’ articular surface were highest during radial-deviation for Scaphoideum with 73.6N and 10.7%BW and during flexion for Lunatum with 58.9N and 8.6%BW. Both contact points on distal radius were located within correspondent articular tray and were dependent to the wrist position. Nevertheless, we could not determine significant shifts as measured in previous studies using pressure contact films.

Discussion: Force vectors within the radiocarpal joint already vary significantly from simple wrist position changes. That applies in particular for load distribution between carpal bones. Peak values could exceed a fifth of body weight.

Significance: To our knowledge the present study is the first that assessed contact forces with corresponding localization of contact points. It provides an initial basis for FEM- and experimental analyses that can be used for musculoskeletal questions as well as for preclinical testing of newly developed radiocarpal joint arthroplasties.

Acknowledgments: The authors thank the Ministry of Economics and Technology of Germany for research grants.

References:

<table>
<thead>
<tr>
<th></th>
<th>$F_{Lun}$</th>
<th>$F_{Scaph}$</th>
<th>$F_R$</th>
</tr>
</thead>
<tbody>
<tr>
<td>extension (20°)</td>
<td>43.8 N</td>
<td>65.7 N</td>
<td>109.5 N</td>
</tr>
<tr>
<td>flexion (20°)</td>
<td>58.9 N</td>
<td>66.4 N</td>
<td>125.4 N</td>
</tr>
<tr>
<td>neutral</td>
<td>49.0 N</td>
<td>62.4 N</td>
<td>111.4 N</td>
</tr>
<tr>
<td>radial-deviation (10°)</td>
<td>37.9 N</td>
<td>73.6 N</td>
<td>111.6 N</td>
</tr>
<tr>
<td>ulnar-deviation (10°)</td>
<td>55.9 N</td>
<td>47.6 N</td>
<td>103.5 N</td>
</tr>
</tbody>
</table>

Table 1: Normalized radiocarpal joint contact forces.
Figure 1: Survey of registered single bones from an overlaid bone-cartilage model into a CT-dataset of a position changed radiocarpal joint to localize cartilage contact points.

ORS 2014 Annual Meeting
Poster No: 0211