Elbow Position Affects Distal Radioulnar Joint Kinematics

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ABSTRACT INTRODUCTION: Previous in vivo and in vitro studies of forearm supination/pronation suggest that distal radioulnar joint kinematics may be affected by elbow flexion. The primary hypotheses tested by this study were that in vivo: 1) ulnar variance changes with elbow flexion and forearm rotation and 2) the arc of forearm rotation changes in relationship to elbow flexion.

METHODS: Changes in radioulnar kinematics during forearm rotation and elbow flexion were studied in 5 healthy subjects (ages 24-31). First, three-dimensional models were obtained by tracing bony contours of the radius and ulna in a solid modeling software (Rhinoceros®, Robert McNeel & Associates, Seattle, WA). Forearms were then imaged using a dual-fluoroscopic imaging system (DFIS) while subjects posed in maximum supination, mid supination, neutral, mid pronation, and maximum pronation at 0°, 45°, 90° flexion angles. Thereafter, the 3D models and the pairs of fluoroscopic images were imported into the modeling software where a virtual fluoroscopic environment was created reproducing the position of the fluoroscopes during the scanning. The in-vivo positions of the radius and ulna were then reproduced by matching the projections of the radius and ulna models to their outlines on the fluoroscopic images. The method has been previously validated to an accuracy of 0.1 mm position and 0.1 degrees rotation (1,2). An anatomically based Cartesian coordinate system was used to measure the 6DOF forearm kinematics.

Significance was pre-defined using an alpha of 0.10. Analysis of Variance (ANOVA) was used to compare the motion of the forearm among the different elbow flexion and rotation angles with Statistica 6.0 (StatSoft, Tulsa OK). Post-hoc testing using a Neuman Keul’s test was performed to evaluate differences between groups.

RESULTS: Mean maximum translation of the radius relative to the ulna was significantly less at 0 degrees v. 90 degrees of elbow flexion (0.54 ± 0.17mm v. 1.28 ± 0.39mm, p=0.05) (Fig 1). Peak distal translation of the radius relative to the ulna occurred in mid-supination and peak proximal translation in mid-pronation. The arc of rotation was significantly smaller at 0 degrees v. 90 degrees of elbow flexion (129 ± 22° v. 152 ± 14° p=0.05) (Table 1). The center of rotation shifted volarly and ulnarily with increasing elbow extension (Fig 2).

DISCUSSION: In this study we investigated the 6DOF kinematics of the normal forearm during elbow flexion and forearm rotation using the DFIS. The forearm showed consistent patterns in all rotations and translations. Elbow position clearly affects the kinematics of the distal radioulnar joint. These findings have relevance to previously postulated injury mechanisms, evaluation of ulnar impaction, and understanding of the soft tissue restraints about the forearm.

The first hypothesis, that ulnar variance changes with elbow flexion, was supported by our findings. These changes came primarily from proximal translation at terminal pronation. These findings are consistent with previous studies examining the influence of elbow flexion and forearm rotation on ulnar variance. In our study, we found a similar magnitude of mean maximum change between maximum pronation and maximum supination (range, 0.54 mm – 1.3mm). However, the maximum amount of distal or proximal translation did not occur at terminal pronation or supination, but occurred mid arc.

The second hypothesis, that arc of rotation changes with elbow flexion, was supported statistically. The total arc of rotation increases with increasing elbow flexion. We observed that as elbow flexion increased, the center of rotation of the radius approached the anatomic center of the ulna head; in addition, the diameter of that arc of rotation decreased significantly with elbow flexion. These findings are relevant in radiographic evaluations of the distal radioulnar joint and ulna variance and understanding injuries of the forearm.

These data provide the basis for future analysis of normal and pathological function of the forearm. Application of three-dimensional solid modeling techniques in conjunction with dual orthogonal fluoroscopy demonstrates that the translation of the radius relative to the ulna, the arc of forearm rotation, and the size of the arc of forearm rotation change with elbow flexion. These findings have implications in radiographic evaluation, understanding of injury mechanisms, and distal radioulnar joint prostheses. Further studies integrating soft tissue structures may be helpful in understanding the contribution of the distal radioulnar ligaments, triangular fibrocartilage, and interosseous membrane to these observations.

REFERENCES:

Figure 1. Mean maximum translation of proximal-distal translation of the radius relative to the ulna. Elbow flexion angle had a statistically significant effect on the mean maximum change between maximal supination/pronation at 0° and 90° flexion.

Table 1. Total arc of rotation, maximum pronation, and maximum supination compared across elbow flexion angle.

<table>
<thead>
<tr>
<th>Elbow Flexion</th>
<th>Total Arc of Rotation</th>
<th>Maximum Pronation</th>
<th>Maximum Supination</th>
</tr>
</thead>
<tbody>
<tr>
<td>0°</td>
<td>129.3 ± 22.2° *</td>
<td>41.1 ± 15.5°</td>
<td>88.2 ± 12.3°</td>
</tr>
<tr>
<td>45°</td>
<td>143.4 ± 11.7° *</td>
<td>57.7 ± 8.3°</td>
<td>85.7 ± 8.0°</td>
</tr>
<tr>
<td>90°</td>
<td>152.8 ± 14.4° *</td>
<td>57.3 ± 5.9°</td>
<td>95.5 ± 18.2°</td>
</tr>
</tbody>
</table>

* p=0.05