Risk of Reduced Subacromial Space in Manual Wheelchair Users Using a Model-Based Approach

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INTRODUCTION
Spinal cord injured (SCI) individuals rely on manual wheelchairs for mobility as well as for recreation and exercise. Therefore, they are dependent on their shoulders for weight bearing during all of their daily activities. Due to this reliance on their shoulders, as well as the lack of geometrical stability in the joint, shoulder-related pain is reported to be as high as 70% [1]. Imaging, as well as cadaveric and animal studies, implicate subacromial space narrowing (that results in mechanical impingement of the interposed rotator cuff tendons) as a primary mechanism for the shoulder pain in this population. Previous reports have used assumed at-risk scapular and glenohumeral angular kinematics (scapular anterior tilt and internal rotation, glenohumeral internal rotation) to assess risk of subacromial space narrowing. A model-based approach was used in this study to predict the proximity of the rotator cuff insertions on the humerus to the underside of the coracoacromial arch. The goal of this project was to compare the risk between three tasks (wheelchair propulsion, weight relief raises, and scapular plane abduction) using both the modeling approach, as well as assumed at-risk angular kinematics, in a population of wheelchair users with reported shoulder pain.

METHODS

Subjects
Fifteen subjects who use manual wheelchairs as their primary means of mobility (gender: 13M, 2F; age: 39 ± 12 yrs; years post-SCI: 14 ± 9 yrs) were recruited according to Institutional Review Board guidelines. The individuals reported shoulder joint pain caused by mechanical impingement (as determined by a licensed physical therapist). Subjects’ injury levels ranged from C6-7 to L2, with one subject who was post-polio.

Kinematic data collection
The subjects’ wheelchairs were placed atop a set of custom aluminum rollers for the kinematic data acquisition. Electromagnetic sensors were attached via double-sided adhesive tape to the sternum, the skin overlying the flat superior surface of the scapular acromion process, and to a thermoplastic cuff secured to the distal humerus on the subject’s painful arm (Fig. 1). Anatomical coordinate systems were defined on each body segment (scapula, humerus, and thorax), and the global coordinate system was defined, according to ISB standards [2]. The three-dimensional position and orientation of the subject’s thorax, scapula, and humerus were collected throughout the dynamic movements at 240Hz using a Liberty (Polhemus, Inc., Colchester, VT) electromagnetic tracking system and accompanying data collection/analysis software, MotionMonitor (Innovative Sports Training, Chicago, IL).

Subjects performed two repetitions of weight relief raises, scapular plane abduction (up to 60 degrees of elevation), and propulsion at a comfortable speed on the aluminum rollers; the final trial was used for analysis. Glenohumeral rotations were expressed using an XZY" Euler sequence [3] and scapulothoracic rotations were expressed using an YXZ" Euler sequence.

Modeling
A CT scan from a single subject of similar height and weight to our median subject was used to generate reconstructed humerus and scapula bone surface models as well as tendon insertion areas on the humerus for the supraspinatus, infraspinatus, and subscapularis (Figure 1). After defining the ISB coordinate systems on the bone model surfaces, each subject’s respective glenohumeral rotation values were used to simulate the motion for all three tasks using a custom Matlab program (Mathworks). The humeral head was centered on the glenoid. At 5% increments across the movement cycles, a
proximity (distance) map was defined from each of the tendon insertion areas on the humerus to the acromion and coracoacromial (CA) ligament. Maps were determined by calculating the Euclidean distance from all vertices in the tendon insertion areas to all vertices on the underside of the acromion and CA ligament. The shortest distance across the proximity maps were saved at each increment of the movements.

Figure 1: Surface models of the scapula (solid gray) and humeral head (meshed gray) with the CA ligament (yellow), subscapularis tendon footprint (blue), supraspinatus tendon footprint (red), and infraspinatus tendon footprint (green).

RESULTS AND DISCUSSION
The kinematics assumed to reduce the subacromial space were selected from the time series curves at four events across the cycles for each movement. Repeated measures ANOVA (p<0.05) were used to assess changes across the three tasks. For both mean and peak rotations, weight relief was found to be consistently at greatest risk (i.e. greater angular values) and scapular plane abduction at least risk (Table 1). However, when using the modeling approach to assess risk (Table 2), propulsion and scapular plane abduction were found to be at greater risk (smaller distances) and weight relief at least risk.

As subacromial impingement risk is directly defined based on glenohumeral motion changes (not indirect shoulder kinematic descriptors including scapulothoracic rotations), it is imperative that future research focus on the glenohumeral articulation rather than on the scapula and humerus motions independently to attempt to define risk. Further, many of the studies which attempt to identify changes in kinematics associated with subacromial risk focus on the scapular plane abduction movement. These data clearly demonstrate that there are differences between tasks, and risk needs to be quantified for the tasks in question rather than translating findings from assessments of other movements.

REFERENCES

ACKNOWLEDGEMENTS
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Table 1: Statistically significant (p<0.05) differences in assumed at-risk kinematics across tasks (SCAP=scapular plane abduction, WR= weight relief, PROP=propulsion). Higher risk (red); lower risk (green).

<table>
<thead>
<tr>
<th>Kinematics</th>
<th>Mean rotations</th>
<th>Peak rotations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scapula internal rotation</td>
<td>SCAP &gt; WR, PROP</td>
<td>WR, PROP &gt; SCAP</td>
</tr>
<tr>
<td>Scapula anterior tilt</td>
<td>WR, PROP &gt; SCAP</td>
<td>WR, PROP &gt; SCAP</td>
</tr>
<tr>
<td>Glenohumeral internal rotation</td>
<td>WR &gt; PROP &gt; SCAP</td>
<td>WR &gt; PROP &gt; SCAP</td>
</tr>
</tbody>
</table>

Table 2: Statistically significant (p<0.05) differences in risk (minimum distances) across tasks for each tendon (SCAP=scapular plane abduction, WR= weight relief, PROP=propulsion). Higher risk (red); lower risk (green).

<table>
<thead>
<tr>
<th>Minimum distances</th>
<th>Acromion</th>
</tr>
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<tbody>
<tr>
<td>Infraspinatus</td>
<td>PROP &lt; WR, SCAP</td>
</tr>
<tr>
<td>Supraspinatus</td>
<td>PROP, SCAP &lt; WR</td>
</tr>
<tr>
<td>Subscapularis</td>
<td>SCAP &lt; PROP &lt; WR</td>
</tr>
</tbody>
</table>

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