TOTAL SHOULDER ARTHROPLASTY WITH SUBSCAPULARIS DEFICIENCY

1 Xabier Larrea, 2 Alain Farron, 1 Dominique Pioletti and 1 Alexandre Terrier
1 Laboratory of Biomechanical Orthopedics, Ecole Polytechnique Federale de Lausanne, Switzerland
2 Department of Orthopedics and Traumatology, CHUV and University of Lausanne, Switzerland

SUMMARY
The subscapularis (SC) is the strongest muscle of the rotator cuff and plays an important role on the stabilization of the gleno-humeral joint. The high incidence of abnormal subscapularis function after total shoulder arthroplasty has been related to a major TSA complication like glenoid component loosening. A numerical musculoskeletal shoulder model was extended to simulate SC deficiency and to study its effects on the contact forces and stresses of the gleno-humeral joint.

METHODS
A numerical musculoskeletal shoulder model was extended to simulate SC deficiency [6]. The model was built from a cadaveric shoulder without any sign of pathology. This model includes the scapula, humerus and six muscles: middle deltoid (MD), anterior deltoid (AD), posterior deltoid (PD), supraspinatus (SS), subscapularis (SC) and infraspinatus combined with teres minoris (IS). Bone geometry was reconstructed from computer tomography (CT) scans of a cadaveric shoulder. Origins and insertions of the muscles were digitized from the same cadaveric shoulder. The reconstructed scapula and humerus were then imported into a CAD software to virtually position a total shoulder arthroplasty prosthesis following the manufacturers recommendations (Aequalis, Tornier SAS, Montbonnon, France).

The original musculoskeletal shoulder model [6] was extended with a new method to obtain muscular force ratios during abduction. Muscular force ratios were estimated by minimizing an error function, based on the difference between measured and predicted muscular activation. The optimization was constrained to satisfy the equilibrium of moments in the glenohumeral joint using the Hill muscle model to relate muscle force and EMG activation [7]. Physiological cross section area (PCSA), optimal muscle length (LOPT) and tendon slack length (L_SL) were taken and adapted from literature [7] (table 1). The optimization algorithm was implemented in Matlab (www.mathworks.com) and used the lsqlin function.

RESULTS AND DISCUSSION

We did a comparative study between a normal shoulder and a shoulder with a partially deficient SC. In order to simulate muscular deficiency, its PCSA was reduced to 50% of the normal value. For each case we extracted the muscle forces, contact pressure, stress in the glenoid component and stress in the cement mantel.

As a result of the SC deficiency, the optimization algorithm predicted an altered distribution of muscle forces. IS muscle force was lower (41%) to satisfy the equilibrium of the arm in the anterior-posterior direction. The weakening of the rotator cuff induced a higher (8%) MD force, which was needed to compensate for the loss of muscular elevation torque. In overall, the deficiency of the SC induced a more vertical muscular resultant force.
The SC deficiency increased the upward migration of the humeral head by 0.5 mm and the posterior translation of 0.3 mm. This translation of the humeral head induced a more eccentric (superior-posterior) glenohumeral contact pattern (figure 1). The maximum and average contact pressure increased by 14% and 13% respectively (figure 1). The maximum von Mises stress in the glenoid increased by 23% (20.6 MPa vs. 15.8 MPa, figure 2). In the cement mantel, the maximum principal stress increased by 36% (11.1 MPa vs. 7.1 MPa, figure 3).

In the normal case, the model predictions were consistent with the literature [6,9,10]. With a deficiency of the SC, the increased MD activity and (superior-posterior) eccentric contact pattern are also consistent with previous numerical studies [11].

CONCLUSIONS
The weakening of the rotator cuff due to a deficient SC muscle reduced its stabilizing function and induced an eccentric articular contact pressure pattern. Stress on both the glenoid component and cement mantel also increased significantly, in particular for abduction angles under 90°, which turn to be the most frequently performed amplitudes during everyday life [12]. These results suggest that the unsuccessful healing of the SC attachment after TSA may challenge the long-term stability of the glenoid component.

ACKNOWLEDGEMENTS
This work was partially supported by Tornier SAS, Montbonnon, France.

REFERENCES

Table 1: Muscle properties included in the model. From Langenderfer et al. [8]. Units: $L_{OPT}$ and $L_{SL}$ [mm], PCSA [cm$^2$].

<table>
<thead>
<tr>
<th></th>
<th>MD</th>
<th>AD</th>
<th>PD</th>
<th>SS</th>
<th>SC</th>
<th>IS</th>
</tr>
</thead>
<tbody>
<tr>
<td>$L_{OPT}$</td>
<td>107.2</td>
<td>107.1</td>
<td>150.2</td>
<td>67.3</td>
<td>104.3</td>
<td>88.1</td>
</tr>
<tr>
<td>$L_{SL}$</td>
<td>12.8</td>
<td>21.5</td>
<td>33.1</td>
<td>24.4</td>
<td>29.5</td>
<td>42.0</td>
</tr>
<tr>
<td>PCSA</td>
<td>7.39</td>
<td>5.46</td>
<td>4.69</td>
<td>3.36</td>
<td>9.49</td>
<td>8.34</td>
</tr>
</tbody>
</table>