Effect of Clavicle Shortening on In Vivo Shoulder Rotations During Abduction Using Biplane Fluoroscopy

+1Giphart, J E; 1Shelburne, K B; 1Duffy, P; 1Krong, J P; 1Peterson, D S; 1Hageman, E; 1North, A; 1Torry, M R; 1Hackett, T R
+1Steadman Philippon Research Institute, Vail, CO; 2Steadman Clinic, Vail, CO; 3University of Denver, Denver, CO
1erik.giphart@sprivail.org

INTRODUCTION:
The clavicle acts as a dynamic strut connecting the upper extremity to the axial skeleton (chest). Clavicle fractures account for approx. 4% of all fractures. Of those fractures, approx. 80% involve the middle third of the clavicle and about 50% are displaced. When treated non-operatively, displaced clavicle fractures will heal with some degree of deformity, most commonly shortening with superior displacement of the medial fragment. A malunion is not well defined in the literature, but most authors consider more than 15 mm of clavicle shortening a malunion.

Controversy exists regarding the operative indications for displaced middle-third clavicle fractures. Clinically, patients with clavicle malunions may not show deficiencies in strength and range of motion (ROM). However, studies have also reported that 25%-50% of patients were dissatisfied with their shoulder function and this was positively correlated with the amount of clavicular shortening. Patients with malunions may experience pain, weakness, fatigability, neurologic symptoms and cosmetic deformity.

Accurate measurement of the in vivo bony motions inside the shoulder is necessary to understand the effects of clavicle malunion on the shoulder complex. Traditional methods for determining 3D dynamic scapular and clavicular motion have included sensors attached to the skin surface or to transcortical bone pins for increased accuracy. In recent years, fluoroscopy has emerged as a new and highly accurate way to measure 3D kinematics of bones inside the body.

The purpose of this study was to determine the 3D acromioclavicular (AC) and glenohumeral (GH) rotations in shoulders with clavicular malunions compared with the intact opposite shoulder during abduction in the scapular plane. It was hypothesized that clavicular malunion causes a significant increase in AC protraction and posterior tilt.

METHODS:
A biplane fluoroscopy system was used to measure the 3D position and orientation of the clavicle, scapula and humerus of both shoulders of 5 male subjects (age: 33±10 yrs, height: 1.82±0.05 m, weight: 78±4 kg) with isolated, unilateral clavicle malunions. Each subject performed continuous and smooth abduction in the scapular plane over 2s.

The biplane fluoroscopy system consisted of two BV Pulsera c-arms (Philips Medical Systems, Best, the Netherlands) which were modified in three ways: 1) the x-ray exposures were synchronized, 2) the generators and image intensifiers were mounted on a custom gantry for maximum movement freedom, and 3) high-speed Phantom v5.1 cameras (Vision Research, Wayne, NJ) were interfaced with the image intensifiers allowing frame rates of up to 1000 fr/s. Biplane fluoroscopy data were collected at 100 Hz, but tracked at 12.5 Hz, because the motions were sufficiently slow. A bilateral high-resolution CT scan was also obtained. This protocol was approved by the governing IRB and informed consent was obtained prior to participation.

The 3D geometries of the clavicle, scapula and humerus were extracted from the CT data (Mimics, Materialize, Ann Harbor, MI). For each frame the 3D bone positions and orientations were estimated using a contour matching algorithm (Model-Based RSA, Medis Specials BV, Leiden, the Netherlands). Coordinate systems and angular measures were determined according to the ISB standard. The AC orientation data were filtered at 2 Hz and normalized to arm elevation angle at 10° increments from 130 down to 30° of arm elevation and averaged across all participants. Ranges of motion were determined for each AC rotation as well. For the GH joint the ROM was determined for GH elevation, as well as the plane of elevation and external rotation angle at 90° of arm elevation.

Table 1. Mean and std. dev. of the ROM in degrees for both shoulders for the three AC rotations as well as GH elevation.

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<th>Fractured</th>
<th>Healthy</th>
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<tr>
<td>Lateral Rot.</td>
<td>28.2(4.1)</td>
<td>29.6(3.6)</td>
</tr>
<tr>
<td>Post tilt</td>
<td>12.3(2.4)</td>
<td>13.4(2.6)</td>
</tr>
<tr>
<td>GH elev.</td>
<td>65.8(5.1)</td>
<td>65.7(8.1)</td>
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A repeated-measures 2-way ANOVA was performed for each AC rotation with independent measure of shoulder (Malunion vs. Healthy) and arm elevation angle (40-130°).

RESULTS:

Figure 1 shows protraction, lateral rotation and posterior tilt of the scapula relative to the clavicle (AC rotations) found in this study. The AC joint on the malunited clavicle side was significantly more protracted (5.3°; p = 0.011); more laterally rotated (4.3°; p = 0.048), and more posteriorly tilted (7.1°; p < 0.001). There was a significant effect of elevation angle for protraction and lateral rotation (Δ; p < 0.001). No significant interaction effects were found. Table 1 shows the range of motion for each rotation. The ROM for the AC rotations and GH elevation was not significantly affected (p > 0.05). The GH joint on the malunited clavicle side was significantly more posterior to the healthy side (4.2°; p = 0.046) and 11.0° more internally rotated (p = 0.014). No other significant differences were found.

DISCUSSION:
Our results indicate that during scapular a clavicular malunion creates an offset in all AC rotations while the respective AC ROMs are preserved. Since all subjects were able to achieve full arm ROM, the other joints of the shoulder complex will have to compensate for these offsets. The protraction and posterior tilt offsets in the AC joint appear to be compensated for by GH plane of elevation and humeral rotation. The offset in the AC lateral tilt does not appear to be compensated for in the GH joint. Measurement of sternoclavicular and scapulothoracic joint rotations will be required to fully understand the alterations in the entire shoulder complex as a result of a clavicle malunion.

REFERENCES:

![Figure 1. Protraction, lateral rotation and posterior tilt of the AC joint as a function of arm elevation angle during abduction in the scapular plane.](image-url)