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Kinematic Evaluation of the Modified Weaver-Dunn Acromioclavicular Joint Reconstruction

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Background: Few reconstructive methods to treat displaced acromioclavicular separations have been evaluated using kinematic data.

Hypothesis: The modified Weaver-Dunn reconstruction restores intact acromioclavicular joint motion during passive scapular plane abduction.

Study Design: Controlled laboratory study.

Methods: Acromioclavicular joint motion was recorded during passive humeral elevation in 3 states: an intact shoulder, an "injured" state in which the acromioclavicular and coracoclavicular ligaments were transected, and finally in a reconstructed state using a modified Weaver-Dunn reconstruction. Measurements were taken with an electromagnetic motion analysis system attached to rigid pins placed in the clavicle, scapula, humerus, and sternum during passive scapular plane humeral elevation.

Results: Total translatory motion of the acromioclavicular joint in the cut state was significantly greater than both the intact and reconstructed states in the medial/lateral (intact, 4.3 mm; cut, 7.9 mm; reconstructed, 2.6 mm), anterior/posterior (intact, 4.8 mm; cut, 6.1 mm; reconstructed, 4.9 mm), and superior/inferior (intact, 4.1 mm; cut, 8.0 mm; reconstructed, 4.8 mm) directions. The maximum and minimum positions of the reconstructed state were significantly more anterior and inferior than in the intact state. A significant increase in acromioclavicular axial rotation was also found between the intact and cut state.

Conclusion: The modified Weaver-Dunn reconstruction was found to restore motion of the acromioclavicular joint to near-intact values, but created a more anterior and inferior position of the clavicle with respect to the acromion.

Clinical Relevance: These kinematic data support the modified Weaver-Dunn reconstruction as a kinematically sound procedure to treat displaced acromioclavicular joint injuries.

Keywords: acromioclavicular joint; shoulder separation; modified Weaver-Dunn reconstruction; shoulder biomechanics
differs from others in that we did not directly displace the clavicle from the acromion, but rather the entire upper extremity kinematic chain was measured in an intact thorax through forces applied during passive humeral elevation in the scapular plane.

MATERIALS AND METHODS

Six shoulders from intact torsos (average age, 62 years; age range, 48-73; 3 female and 3 male; 3 right and 3 left), including all muscles, soft tissues, chest wall, and vertebral columns, were allowed to thaw at room temperature overnight before testing. Each specimen was mounted upright on a jig to allow free motion of the arm and shoulder girdle. Bicortical threaded Kirschner wires were then inserted into the midclavicle, scapular spine, sternum, and deltid insertion on the humerus. Electromagnetic motion sensors (Polhemus Inc, Colchester, Vermont) were rigidly attached to these pins. The Polhemus system is a 6 degree of freedom electromagnetic tracking device that uses a global positioning transmitter and receivers to capture 3-dimensional position and orientation. Synchronous data collection at a sampling rate of 30 Hz per sensor recorded the location of each individual bone segment relative to the transmitter. A distance of approximately 200 to 500 mm was maintained between the transmitter and the sensors, which was within the reported range of 100 to 700 mm for optimal accuracy. The accuracy of this alternating current tracking device has been reported as 0.3 mm and 0.3°.5,17

Anatomic landmarks of the intact specimen over each bone segment were palpated and digitized by an experienced physical therapist (P.M.L.) using a stylus before dissection. This establishment of local coordinate systems for the specimens was performed all trials on all specimens in a similar manner. Posttesting dissections were performed to verify there were no rotator cuff tears, glenohumeral joint arthritis, or capsulolabral injuries.

Statistics were computed using SAS 9.1.3 for Windows (SAS Institute, Cary, North Carolina). For each plane (anterior/posterior, medial/lateral, superior/inferior), we performed a 2-way analysis of variance with repeated measures of the dependent measures (minimum, maximum, and total excursion) by the classifications of specimen, state (intact, cut, reconstructed), and trial. Significance was considered for $\alpha = .01$ was performed for the clavicular excursion, minimum position, and maximum position in each plane.

RESULTS

Data for the total excursion of the distal clavicle on the medial acromion (Figure 2), minimum position, and maximum position of the clavicle related to the acromion in the medial/lateral (Figure 3), anterior/posterior (Figure 4), and superior/inferior (Figure 5) planes is displayed in graphic format. Positive values indicate anterior, medial, and superior positions. Only significant values will be discussed below. Data for excursion in each plane from a single trial of raising the arm into scapular abduction are represented in Figure 6.

The average medial/lateral total excursion in the intact shoulders was 4.3 mm ($\pm$ 2.0 mm). The excursion increased to 7.9 mm with a standard deviation (SD) of $\pm$3.4 mm in
the cut state, and in the reconstructed shoulders, the average excursion was 2.6 mm (SD ± 4.9 mm). Significant differences were found between the excursions of the intact and cut states (P < .01), and between the excursions of the cut and reconstructed states (P < .01). The statistical power for the clavicular excursion, minimum position, and maximum position in the medial/lateral plane was 0.99, 0.99, and 0.53, respectively.

The average excursion in the anterior/posterior planes for the intact shoulders was 4.8 mm (SD ± 5.0 mm). The excursion increased to 6.1 mm (SD ± 6.3 mm) in the cut state, and was 4.9 mm (SD ± 5.1 mm) after reconstruction. Statistical significance was found in comparing the excursion versus cut states (P < .01) and cut versus reconstructed states (P < .01). In the reconstructed state, the average minimum position of the clavicle compared to the intact was 2.6 mm and 2.1 mm more anterior compared with the intact (P < .01) and cut (P < .01) states, respectively. The statistical power for the clavicular excursion, minimum position, and maximum position in the anterior/posterior plane was 0.82, 0.99, and 0.99, respectively.

In the superior/inferior plane, the average superior excursion of the clavicle in intact shoulders was 4.1 mm (SD ± 3.2 mm), compared with 8.0 mm (SD ± 6.8 mm) of excursion in cut shoulders and 4.8 mm (SD ± 3.3 mm) of
excursion after reconstruction. There was a significant difference between the intact and cut states ($P < 0.01$), as well as between the cut and reconstructed states ($P < 0.05$). The maximum superior position of the clavicle in relation to the acromion changed from 7.0 mm in the intact state, 9.1 mm in the cut state, and 3.2 mm in the reconstructed state. These superior position changes were significant between the intact and cut states ($P < 0.05$), intact and reconstructed states ($P < 0.01$), and the cut and reconstructed states ($P < 0.01$). The minimum inferior position changed from 3.0 mm in the intact state, 1.1 mm in the cut state, and $-1.6$ mm in the reconstructed state (with negative values indicating a more inferior position). There were significant differences between the minimum inferior positions of the intact and reconstructed states ($P < 0.01$) and the cut and reconstructed states ($P < 0.01$). Thus, in the reconstructed state, the clavicle assumed a significantly more inferior position in relation to the acromion. There was no significance between the minimum inferior positions of the intact and cut states. The statistical power for the clavicular excursion, minimum position, and maximum position in the superior/inferior plane was 0.74, 0.99, and 0.99, respectively.

Figure 6. Plot of excursions in each plane for a single trial of elevation of the arm in the scapular plane.

Posterior acromioclavicular long axis rotation with passive scapular plane abduction increased from an average of 23.5° (SD ± 5.7°) in the intact shoulders to 31.0° (SD ± 6.0°) on the transected shoulders. This value was restored to 27.1° (SD ± 4.8°) in the reconstructed series (Figure 7). There were significant differences between the intact and cut states ($P < 0.01$), between the cut and reconstructed states ($P < 0.01$), and between the intact and reconstructed states ($P < 0.01$).

Figure 7. Posterior acromioclavicular axial rotation during passive scapular plane abduction. Error bars indicate standard error of the mean.

DISCUSSION

In this study, we sought to determine if a modified Weaver-Dunn reconstruction would re-create intact acromioclavicular joint motion. In spite of various methods being proposed to treat symptomatic displaced acromioclavicular joint injuries, few methods have been evaluated using kinematic data. Our data show that clavicular translatory motion on the acromion was restored to within 1.7 mm of total excursion in the medial/lateral direction, within 0.1 mm in the anterior/posterior direction, and within 0.7 mm in the superior/inferior direction. It has been reported that the most common clinical pathologic displacements of the distal clavicle with injuries are superior and posterior motions; the Weaver-Dunn reconstruction was found to restore these joint motions well. However, the position of the clavicle with respect to the acromion was more inferior after reconstruction by an
average of 4.6 mm. This position change was likely due to the modified Weaver-Dunn technique, which tethers the clavicle from its superior-riding injured state. We believe this amount is small and may not be clinically significant, but it may require careful assessment in patients to make sure this inferior clavicular position does not impinge on the supraspinatus muscle. We also found that the clavicle was 2.6 mm more anterior at the most anterior point in the reconstructed state compared to the intact specimens. These values agree with the observation by Morrison and Lemos\cite{18} that when the clavicle was cerclaged to the coracoid, the clavicle was tethered more anteriorly due to the force vector applied by the cerclage. Our study did not investigate the actual strength of this reconstruction and previous studies have investigated this parameter.\cite{7,21}

In a 1944 landmark article by Inman et al.,\cite{10} measuring the angle of a pin placed in the clavicle of a living subject during both humeral abduction and elevation, they reported an average clavicular posterior rotation of approximately 50° relative to the thorax. In our cadaveric study, we measured an average posterior clavicular rotation on the acromion (acromioclavicular joint) of 23.5° in the intact state during humeral elevation, which is approximately half of what the Inman article had reported. This observation could be due to differences in technologies used to measure rotation, as well as differences between cadaveric passive range of motion versus active in vivo range of motion. Studies using live subjects are in progress and will further address this variation.

As with most cadaveric in vitro biomechanical studies, we recognize that there were some limitations compared with in vivo studies. First, our testing assessed passive motion only. The effects of muscle contractions, especially for the deltoid and trapezius muscles, could change the amount of motion with type III acromioclavicular joint injuries in vivo. In addition, we only tested acromioclavicular joint motion with scapular plane abduction. However, this movement has been chosen to be the standard test motion for assessing shoulder function for many in vitro and biomechanical studies\cite{6,12,15} because it allows uniformity in comparisons among studies for the complex motion seen at the shoulder girdle. In comparison with previous studies,\cite{6,9,19,24} this study was unique in that by using intact torsos, the effects of sternoclavicular, scapulothoracic, and glenohumeral joint motion were not compromised to assess acromioclavicular joint motion.

Our study also validated a biomechanical testing protocol for measuring acromioclavicular kinematics 3-dimensionally using bicortical pins, which will be used for ongoing in vivo testing of study participants. It is recommended that future studies compare the kinematics of the various techniques used to treat injuries of the acromioclavicular joint.

CONCLUSION

Overall, the modified Weaver-Dunn reconstruction was found to stabilize abnormal motion associated with acromioclavicular injuries, especially against motion in the superior and posterior directions. Near-normal values were restored for acromioclavicular long axis rotation and excursion in all directions. This study also demonstrated that the modified Weaver-Dunn reconstruction induced a slight anteroinferior position of the clavicle in relation to the acromion, which may require careful assessment in some patients. In conclusion, despite the resultant anteroinferior relationship of the acromion and clavicle, this study supports the use of the modified Weaver-Dunn procedure for reconstruction of acromioclavicular injuries, because it approximates intact motion as compared with the acromioclavicular ligament transected state.

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