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Kinematic Evaluation of the Modified Weaver-Dunn Acromioclavicular Joint Reconstruction

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Abstract

Background—Few reconstructive methods to treat displaced acromioclavicular separations have been evaluated using kinematic data. The purpose of this study was to evaluate the efficacy of the modified Weaver-Dunn reconstruction to restore acromioclavicular motion during humeral range of motion.

Hypothesis—We hypothesized that the modified Weaver-Dunn reconstruction restores intact acromioclavicular joint motion during passive scapular plane abduction.

Study Design—Controlled laboratory study using cadaveric torso specimens.

Materials and Methods—Acromioclavicular joint motion was recorded during passive humeral elevation in three states: an intact shoulder, an ‘injured’ state where 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—This kinematic data supports the modified Weaver-Dunn reconstruction as a kinematically sound procedure to treat displaced acromioclavicular joint injuries.

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Keywords

acromioclavicular joint; shoulder separation; modified Weaver-Dunn reconstruction; shoulder biomechanics

Introduction

Controversy exists as to which surgical treatment of symptomatic type III and types IV through VI acromioclavicular separations is superior. A number of biomechanical studies have looked at various reconstructions or repair techniques using forces directly applied to the clavicle or acromion.^{2,7,11,24} These studies provide useful information on the strength of the repair but do not take into account other clinically relevant forces through the construct such as scapulohumeral or sternoclavicular motion.

The purpose of this biomechanical study was to test the anatomic linkages between the clavicle and scapula to better understand their relationships during passive humeral motion in an intact state, an injured state where the acromioclavicular and coracoclavicular ligaments were cut, and then in a reconstructed state using a modification of the technique described by Weaver and Dunn.²³ Described as one of the most successful techniques to treat acromioclavicular joint injuries, their original description reported on a transfer of the coracoacromial ligament from the acromion into the end of the resected distal clavicle.¹⁹ Modifications to this technique have involved the addition of augmentations between the clavicle and the coracoid to protect the transferred coracoacromial ligament during early healing.¹⁸ Our hypothesis was that a modified Weaver-Dunn reconstruction would restore acromioclavicular joint motion to near normal ranges during passive scapular plane abduction. This study 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, 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 prior to 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 mid-clavicle, scapular spine, sternum, and deltoid insertion on the humerus. Electromagnetic motion sensors (Polhemus Inc., Colchester, VT, USA) were rigidly attached to these pins. The Polhemus system is a 6 degree-of-freedom electromagnetic tracking device which utilizes 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 200–500 mm was maintained between the transmitter and the sensors, which was within the reported range of 100 to 700 mm for optimal accuracy.

¹ The accuracy of this alternating current (AC) tracking device has been reported as 0.3 mm and 0.3°.^{5,17}

Anatomical landmarks of the intact specimen over each bone segment were palpated and digitized by an experienced physical therapist using a stylus prior to dissection. This establishment of local coordinate systems for each segment was based on International Society of Biomechanics recommended protocols for the shoulder²⁴ and accepted research practice.^{12,25} The high reliability of this technique has been established.¹⁵ Subsequently, rotation and excursion information could be provided for segments relative to each other based on

anatomical frames of reference.²⁵ Using the Polhemus sensors attached to the bicortical Kirschner wires, the Polhemus system recorded the three-dimensional long axis rotation of the distal clavicle relative to the acromion and excursions in the medial/lateral, anterior/posterior, and superior/inferior directions were recorded while the humerus was passively moved through three cycles of scapular plane elevation at a forty degree angle, measured with a goniometer, forward of coronal plane abduction. One cycle consisted of movement between maximum and minimum abduction of the arm with each elevation and lowering motion being performed in three second intervals. While the amount of interspecimen maximum and minimum abduction was variable secondary to subject specific range of motion differences, the amount of intraspecimen abduction was held constant across each condition (intact, transected, and reconstructed) so as to not alter the effect of the transection or reconstruction. The same investigator conducted all trials on all specimens in a similar manner.

After the intact shoulder joint was tested, an anterior incision was made over the acromioclavicular joint and blunt dissection through the deltopectoral interval allowed access to the coracoid. Transection of the acromioclavicular and coracoclavicular (trapezoid and conoid) ligaments was then performed to simulate a type III acromioclavicular separation, and the motion data was collected using the previously described motion protocol. The acromioclavicular joint was then reconstructed with the arm in neutral position using a modified Weaver-Dunn reconstruction performed by the same senior faculty member on the shoulder service (RFL). One centimeter of the distal end of the clavicle was resected with an oscillating saw and five mm of the distal medullary cavity was hollowed out to prepare it for the coracoacromial ligament transfer. The coracoacromial ligament was then dissected off of the acromion, and a whipstitch of its distal end was performed with number 5 Ticron (Tyco Health Care, Norwalk, CT). The sutures in the coracoacromial ligament were then pulled into drill holes through the posterior cortex of the distal clavicle to complete the transfer of the coracoacromial ligament. Further stabilization of the clavicle was further augmented with a number 5 Mersilene tape (Johnson and Johnson, Somerville, NJ) cerclage, looping inferior to the coracoid and through a 4 mm superior-to-inferior drill hole at the coracoclavicular ligament insertion on the clavicle. The clavicle was reduced to the acromion so that their inferior surfaces were qualitatively observed to be co-planar, similar to a clinical reconstruction (Figure 1). Preconditioning of the reconstruction was performed by moving the arm through ten cycles of maximum-minimum abduction. The final data set was then collected using the previously described motion protocol. Post-testing 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 ((c) 2003 SAS Institute, Cary, North Carolina, USA). For each plane (anterior/posterior, medial/lateral, superior/inferior), we performed a two-way ANOVA 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 $p < .05$. A power analysis with $\alpha = 0.01$ 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 graphical format. Positive values indicate anterior, medial, and superior positions. Only significant values will be discussed in the following section. Data for excursion in each plane from a single trial of raising the arm into scapular abduction is represented in Figure 6.

The average medial/lateral total excursion in the intact shoulders was 4.3 mm (± 2.0 mm). The excursion increased to 7.9 mm with a standard deviation (SD) of ± 3.4 mm in the cut state, and in the reconstructed shoulders, the average excursion was 2.6 mm with an SD of ± 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 with an SD of ± 5.0 mm. The excursion increased to 6.1 mm with an SD of ± 6.3 mm in the cut state, and was 4.9 mm with an SD of ± 5.1 mm following reconstruction. Statistical significance was found in comparing the excursion between the intact 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 acromion was 2.6 mm and 2.1 mm more anterior compared to 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 with an SD of ± 3.2 mm, compared to 8.0 mm with an SD of ± 6.8 mm of excursion in cut shoulders, and 4.8 mm with an SD of ± 3.3 mm of excursion following reconstruction. There was a significant difference between the intact and cut states ($p < 0.01$), as well as between the cut and reconstructed states ($p < .05$). 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 ($p < .05$), intact and reconstructed states ($p < .01$), and the cut and reconstructed states ($p < .01$). 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 ($p < .01$), and the cut and reconstructed states ($p < .01$). 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.

Posterior acromioclavicular long axis rotation with passive scapular plane abduction increased from an average of 23.5 degrees with an SD of ± 5.7 degrees in the intact shoulders to 31.0 degrees with an SD of ± 6.0 degrees on the transected shoulders. This value was restored to 27.1 degrees with an SD of ± 4.8 degrees in the reconstructed series (Figure 7). There were significant differences between the intact and cut states ($p < .01$), between the cut and reconstructed states ($p < .01$), and between the intact and reconstructed states ($p < .01$).

Discussion

In this study, we sought to determine if a modified Weaver-Dunn reconstruction would recreate intact acromioclavicular joint motion. In spite of various methods being proposed to treat symptomatic displaced acromioclavicular joint injuries,^{3–4,7,11,13–14,18,20–23} few methods have been evaluated using kinematic data.² Our data shows that clavicular translatory motion on the acromion was restored to within 1.7 mm of total excursion in the medial/lateral direction; to within 0.1 mm in the anterior/posterior direction; and within 0.7 mm in the superior/inferior direction. Since 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.⁹ 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 Morrison's observation that when the clavicle was cerclaged to the coracoid, the clavicle was tethered more anteriorly due to the force vector applied by the cerclage.¹⁸ Our study did not investigate the actual strength of this reconstruction and previous studies have investigated this parameter.^{7,21}

In a historical paper by Inman et al. in 1944, 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 degrees relative to the thorax.¹⁰ In our cadaveric study, we measured an average posterior clavicular rotation on the acromion (acromioclavicular joint) of 23.5 degrees 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 to *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 grade 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,^{8,12,16} because it allows uniformity in comparisons among studies for the complex motion seen at the shoulder girdle. In comparison to previous studies,^{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 three-dimensionally using bicortical pins, which will be used for ongoing *in vivo* testing of subjects. It is recommended that future studies compare the kinematics of the various techniques used to treat injuries of the acromioclavicular joint.

Conclusions

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 approximated intact motion as compared to the acromioclavicular ligament transected state.

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Figure 1.
Illustration of the modified Weaver Dunn reconstruction with attached bicortical testing pins in the clavicle, scapular spine, and humerus with attached tracking sensors (right shoulder).
[CA = Coracoacromial]

Figure 2.

Distal clavicular excursion on the medial acromion in the anterior/posterior, medial/lateral, and superior/inferior planes during scapular plane abduction. Positive values indicate anterior, medial, and superior translation directionality. Error bars indicate standard error of the mean.

Figure 3. Maximum and minimum distal clavicular position on the medial acromion in the medial/lateral plane during scapular plane abduction. Error bars indicate standard error of the mean.

Figure 4. Maximum and minimum distal clavicular position on the medial acromion in the anterior/posterior plane during scapular plane abduction. Error bars indicate standard error of the mean.

Figure 5. Maximum and minimum distal clavicular position on the medial acromion in the superior/inferior plane during scapular plane abduction. Error bars indicate standard error of the mean.

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

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