The American Journal of Sports Medicine

http://ajs.sagepub.com/

Kinematic Evaluation of the Modified Weaver-Dunn Acromioclavicular Joint Reconstruction

Robert F. LaPrade, Daren J. Wickum, Chad J. Griffith and Paula M. Ludewig

Am J Sports Med 2008 36: 2216 originally published online June 6, 2008
DOI: 10.1177/0363546508319048

Kinematic Evaluation of the Modified Weaver-Dunn Acromioclavicular Joint Reconstruction

Robert F. LaPrade,*† MD, PhD, Daren J. Wickum,† MD, Chad J. Griffith,† and Paula M. Ludewig,‡ PhD, PT
From the †Department of Orthopaedic Surgery and the ‡Department of Physical Medicine and Rehabilitation, University of Minnesota, Minneapolis, Minnesota

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

Controversy exists as to which surgical treatment of symptomatic type III and type 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 in which 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, the original Weaver Dunn technique involved 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

*Address corresponce to Robert F. LaPrade, MD, PhD, Professor, Department of Orthopaedic Surgery, University of Minnesota, 2450 Riverside Avenue, R200, Minneapolis, MN 55454 (e-mail: lapra001@umn.edu).

No potential conflict of interest declared.

The American Journal of Sports Medicine, Vol. 36, No. 11
DOI: 10.1177/0363546508319048

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 deltoid 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.[1] 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 each segment was based on the International Society of Biomechanics recommended protocols for the shoulder[25] 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 anatomic frames of reference.[25] With use of the Polhemus sensors attached to the bicortical Kirschner wires, the Polhemus system recorded the 3-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 3 cycles of scapular plane elevation at a 40° 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 3-second intervals. Although 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 were 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 shoulder surgeon (R.F.L.). One centimeter of the distal end of the clavicle was resected with an oscillating saw and 5 mm of the distal medullary cavity was hollowed out to prepare the clavicle 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 No. 5 Ticron (Tyco Health Care, Norwalk, Connecticut). 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. Stabilization of the clavicle was further augmented with a No. 5 Mersilene tape (Ethicon, Johnson & Johnson, Somerville, New Jersey) 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 coplanar, similar to a clinical reconstruction (Figure 1). Preconditioning of the reconstruction was performed by moving the arm through 10 cycles of maximum-minimum abduction. The final data set was then collected using the previously described motion protocol. 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 $P < .05$. A power analysis with $\alpha = .01$ 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 (± 2.0 mm). The excursion increased to 7.9 mm with a standard deviation (SD) of ±3.4 mm in

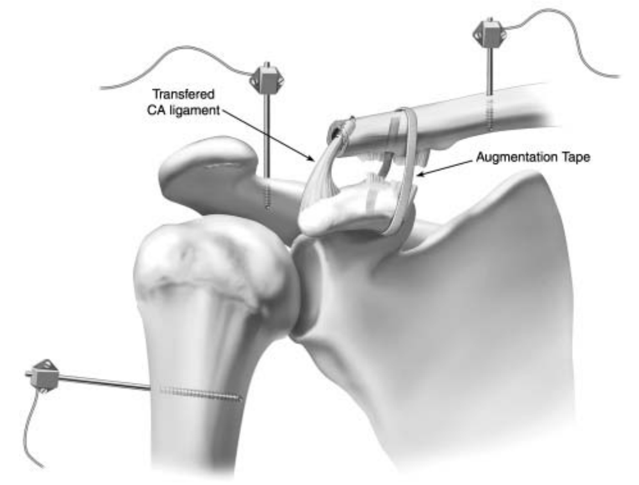

Figure 1. Illustration of the modified Weaver-Dunn reconstruction with attached bicortical testing pins in the clavicle, scapular spine, and humerus with attached tracking sensors (right shoulder). CA, coracoacromial.

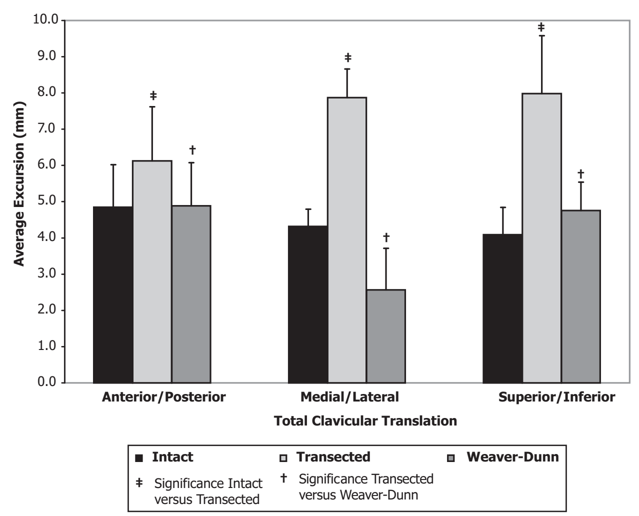

Figure 2. Distal clavicular excursion on the medial acromion in the anterior/posterior, medial/lateral, and superior/inferior planes during scapular plane abduction. Positive values indicate anterior, medial, and superior translation directionality. Error bars indicate standard error of the mean.

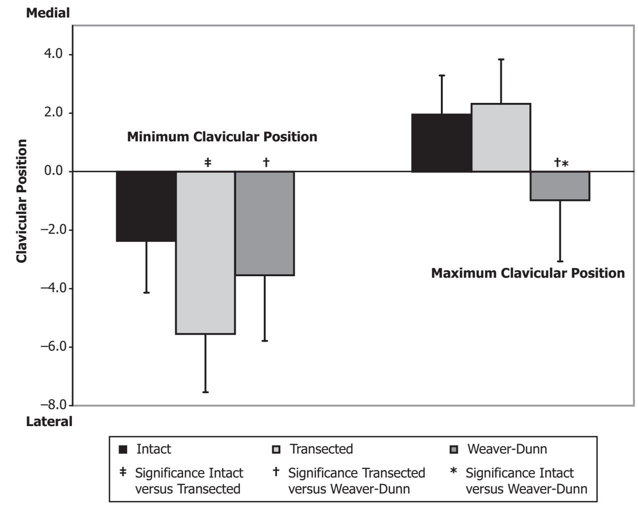

Figure 3. Maximum and minimum distal clavicular position on the medial acromion in the medial/lateral plane during scapular plane abduction. Error bars indicate standard error of the mean.

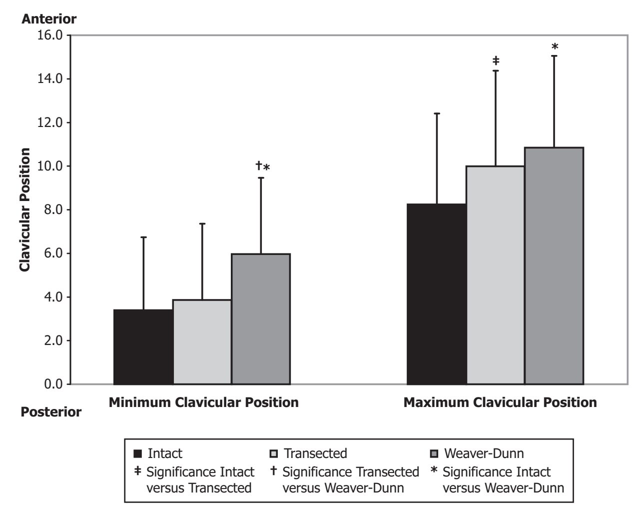

Figure 4. Maximum and minimum distal clavicular position on the medial acromion in the anterior/posterior plane during scapular plane abduction. Error bars indicate standard error of the mean.

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 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 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

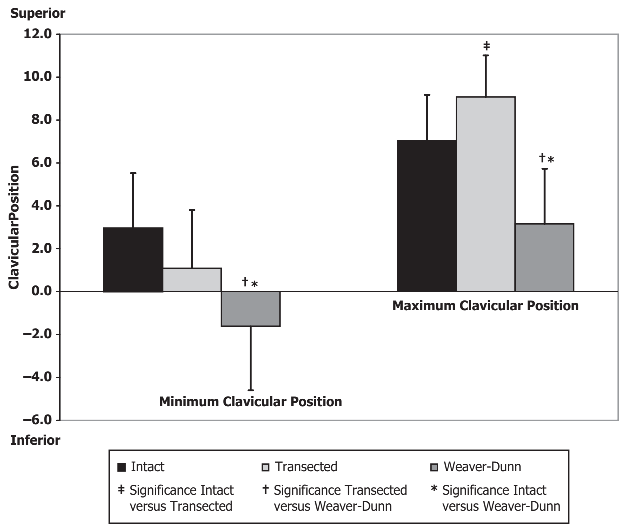

Figure 5. Maximum and minimum distal clavicular position on the medial acromion in the superior/inferior plane during scapular plane abduction. Error bars indicate standard error of the mean.

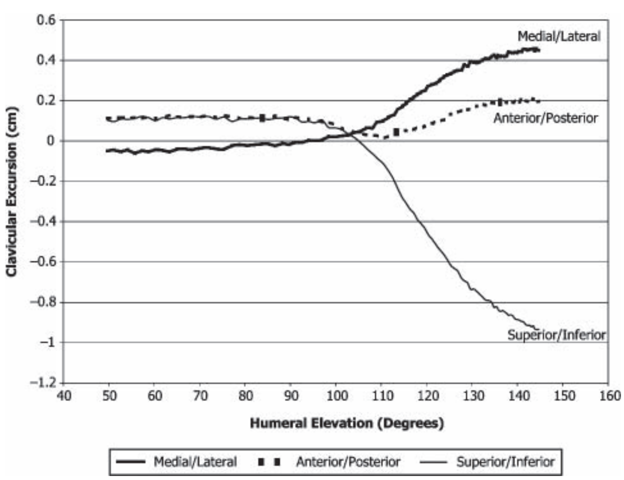

Figure 6. Plot of excursions in each plane for a single trial of elevation of the arm in the scapular plane.

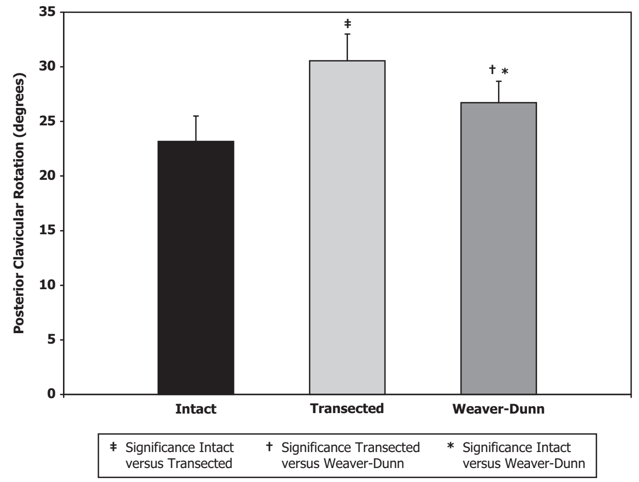

Figure 7. Posterior acromioclavicular axial rotation during passive scapular plane abduction. Error bars indicate standard error of the mean.

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 ($P < .05$). 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° (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 ($P < .01$), 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 re-create 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 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.[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 the observation by Morrison and Lemos[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.[7,21]

In a 1944 landmark article by Inman et al,[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[8,12,15] because it allows uniformity in comparisons among studies for the complex motion seen at the shoulder girdle. In comparison with 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 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.

ACKNOWLEDGMENT

This project was supported in part by grants from the Minnesota Medical Foundation and by the National Institutes of Health (NIH K01 HD042491). The authors thank Fred Wentorf, PhD, for his assistance with the biomechanics testing portion of this study and Paul Lender for his statistical analysis of the data.

REFERENCES

1. An KN, Jacobsen C, Berglund LJ, Chao EYS. Application of a magnetic tracking device to kinesiologic studies. *J Biomech.* 1988;21:613-620.
2. Bargren J, Erlanger S, Dick M. Biomechanics and comparison of two operative methods of treatment of complete acromioclavicular separation. *Clin Orthop Relat Res.* 1978;130:267-272.
3. Berg E. A preliminary report of acromioclavicular joint reconstruction with clavicular corticotomy. *J Shoulder Elbow Surg.* 1995;4:135-140.
4. Breslow M, Jazrawi L, Bernstein A, Kummer FJ, Rokito AS. Treatment of acromioclavicular joint separation: suture or suture anchors? *J Shoulder Elbow Surg.* 2002;11:225-229.
5. Day JS, Murdoch DJ, Dumas GA. Calibration of position and angular data from a magnetic tracking device. *J Biomech.* 2000;33:1039-1045.
6. Debski RE, Parsons IM, Woo SLY, Fu FH. Effect of capsular injury on acromioclavicular joint mechanics. *J Bone Joint Surg Am.* 2001;83:1344-1351.
7. Deshmukh A, Wilson D, Zilberfarb J, Perlmutter GS. Stability of acromioclavicular joint reconstruction: biomechanical testing of various surgical techniques in a cadaver model. *Am J Sports Med.* 2004;32:1492-1498.
8. Doody SG, Freedman L, Waterland JC. Shoulder movements during abduction in the scapular plane. *Arch Phys Med Rehabil.* 1970;51:595-604.
9. Fukuda K, Craig EV, An K-N, Cofield RH, Chao EY. Biomechanical study of the ligamentous system of the acromioclavicular joint. *J Bone Joint Surg Am.* 1986;68:434-440.
10. Inman VT, Saunders JB, Abbott LC: Observations on the function of the shoulder joint. *J Bone Joint Surg.* 1944;26:1-30.
11. Jerosch J, Filler T, Peuker E, Greig M, Siewering Y. Which stabilization technique corrects anatomy best in patients with AC-separation: an experimental study. *Knee Surg Sports Traumatol Arthrosc.* 1999;7:365-372.
12. Karduna AR, McClure PW, Michener LA, Sennett B. Dynamic measurement of three-dimensional scapular kinematics: a validation study. *J Biomech Eng.* 2001;123:184-190.
13. Kawabe J, Watanabe R, Sato M. Treatment of complete acromioclavicular separation by coracoacromial ligament transfer. *Clin Orthop Relat Res.* 1984;185:222-227.

14. LaPrade RF, Hilger B: Coracoclavicular ligament reconstruction using a semitendinosus graft for failed acromioclavicular separation surgery. *Arthroscopy.* 2005;21:1277e1-e5.
15. Ludewig PM, Cook TM. Alterations in shoulder kinematics and associated muscle activity in people with symptoms of shoulder impingement. *Phys Ther.* 2000;80:276-291.
16. Mell AG, LaScalza S, Guffey P, et al. Effect of rotator cuff pathology on shoulder rhythm. *J Shoulder Elbow Surg.* 2005;14:58S-64S.
17. McKellop H, Hoffman R, Sarmiento A, Ebramzadeh E. Control of motion of tibial fractures with use of a functional brace or external fixator. *J Bone Joint Surg Am.* 1993;75:1019-1025.
18. Morrison D, Lemos M. Acromioclavicular separation: reconstruction using synthetic loop augmentation. *Am J Sports Med.* 1995;23:105-110.
19. Motamedi AR, Blevins FT, Willis MC, McNally TP, Shahinpoor M. Biomechanics of the coracoclavicular ligament complex and augmentations used in its repair and reconstruction. *Am J Sports Med.* 2000;28:380-384.
20. Powers J, Bach P. Acromioclavicular separations: closed or open treatment? *Clin Orthop Relat Res.* 1974;104:213-223.
21. Taft T, Wilson F, Oglesby J. Dislocation of the acromioclavicular joint: an end result study. *J Bone Joint Surg Am.* 1987;69:1045-1052.
22. Urist M. Complete dislocations of the acromioclavicular joint: the nature of the traumatic lesion and effective methods of treatment with an analysis of forty-one cases. *J Bone Joint Surg.* 1946;28:813-837.
23. Weaver J, Dunn H. Treatment of acromioclavicular injuries, especially complete acromioclavicular separation. *J Bone Joint Surg Am.* 1972;54:1187-1194.
24. Wilson R, Moses J, Zilberfarb J, Hayes WC. Mechanics of coracoacromial ligament transfer augmentation for acromioclavicular joint injuries. *J Biomech.* 2005;38:615-618.
25. Wu G, van der Helm FCT, Veeger HEJ, et al. ISB recommendation on definitions of joint coordinate systems of various joints for the reporting of human joint motion. Part II: shoulder, elbow, wrist and hand. *J Biomech.* 2005;38:981-992.