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The Stabilizing Effect of Various Implants on the Torn Acromioclavicular Joint

A Biomechanical Study

H. Kiefer, L. Claes, C. Burri, and J. Holzwarth

Laboratory for Experimental Traumatology, University of Ulm, Oberer Eselsberg, D-7900 Ulm, Federal Republic of Germany

Summary. A biomechanical in vitro test was performed to determine the stabilizing effect of various implants for the surgical treatment of the torn acromioclavicular joint. In a specially designed testing device, plastic and cadaver specimens of the shoulder girdle were stressed in various ways. Different dislocations between the acromion and the clavicle and between the clavicle and the coracoid were determined, as well as the stiffness of the implants. A convenient stabilizing effect combined with less rigid fixation to secure the newly treated AC joint was provided by K-wire fixation with cerclage. Interfering shear and bending stresses could be avoided with this method, while the other implants showed various disadvantages. From a biomechanical point of view, a carbon-fiber ligament replacement provides sufficient stability in cases of chronic acromioclavicular separation.

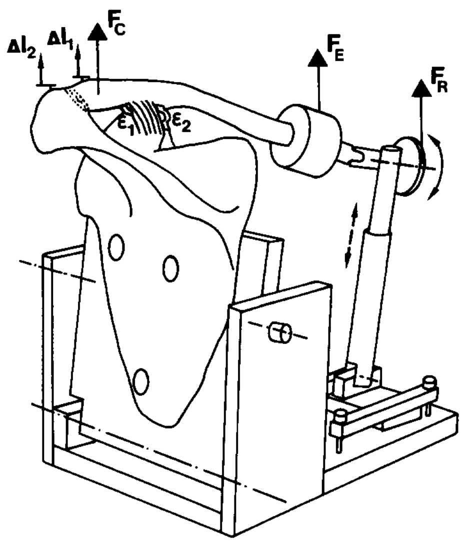
Zusammenfassung. Die stabilisierende Wirkung verschiedener bei der Behandlung der Schultereckgelenkssprengung Verwendung findender Implantate wurde in einem biomechanischen Test in vitro untersucht. In einer speziellen Testvorrichtung wurden Kunststoffmodelle und Leichenpräparate auf verschiedene Weise beansprucht. Neben der Höhe der acromioclavicularen Gelenksstufe wurden die coracoclaviculare Abstandszunahme wie auch die Implantatssteifigkeit bestimmt. Ein guter Stabilisationseffekt, verbunden mit einer zufriedenstellenden, weniger rigiden Fixation des AC-Gelenkes zum Schutz des frisch rekonstruierten Kapselbandapparates, wurde für die Spickdrahttransfixation mit kombinierter Cerclage ermittelt. Die auftretenden Scher- und Biegekräfte können mit dieser Methode neutralisiert werden, während die anderen Verfahren zum Teil gravierende Nachteile aufweisen. In Fällen chronischer AC-Gelenk-Instabilität kann mit einem Kohlenstoffaserband biomechanisch genügende Stabilität erzielt werden.

Offprint requests to: Dr. Hartmuth Kiefer (address above)

The separation of the acromioclavicular joint, type Tossy III, is generally treated by surgery. The torn ligaments and the capsule are sutured and the joint is temporarily immobilized by an implant to secure the healing ligaments [1, 2, 4, 5, 7, 8]. For this purpose, various implants and grafts have been used. In this investigation, the stabilizing and therefore suture-securing effect of six commercially available implants and of one alloplastic ligament replacement was studied in vitro.

The acromioclavicular (AC) joint is normally stressed in two ways. First, in opposing the tensile force of the trapezius muscle at the lateral clavicle, the weight of the arm causes shear stress in the AC joint. Rupture of the joint leads to the appearance of a "step" between the acromion and the clavicle. Second, when abduction and flexion of the arm are performed, movement of the scapula causes relative motions between the scapula and the clavicle to occur [6, 9]. The angle between the clavicle and the scapular spine increases with progressive flexion of the arm. In addition, posterior rotation of the clavicle up to 40° has been measured [6, 9]. These relative motions are of a similar magnitude in flexion and abduction of the arm [6].

While the kinematics of the AC joint are well known, a review of the literature did not reveal any



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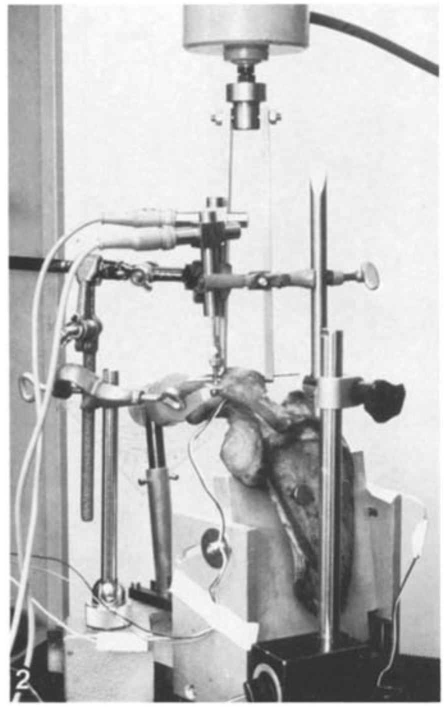

Fig. 1. Testing device. Scapula fixed, clavicle mounted with multi joint system. F_C, Force cranially; F_E, elevation; F_R, rotational moment; ε_1, ε_2, strain in the trapezoid, conoid ligaments; Δl_1-Δl_2, AC step

Fig. 2. Mounted specimen in the materials-testing machine

information concerning the magnitude of the forces acting through the normal acromioclavicular joint. Consequently, surgical repair processes may adequately account for the motion in the repaired joint, but one may question whether they account for the forces in the joint. This study was aimed at quantitative measurement of the effect of simulated joint forces on various implants to the sutured ligaments.

Material and Methods

A special device was constructed which could be adapted to the various anatomical features of the AC joint. The scapula-clavicle specimens were clamped in such a manner as to allow the scapula to be fixed, and the forces were introduced via the clavicle. A multi joint system at the sternal end of the clavicle allowed its free rotation (Fig. 1). Seven standardized plastic models without ligaments and 12 fresh specimens from the left shoulders of human cadavers were used for this study. The cadaveric specimens were kept moist with Ringer's solution during the investigation period. The clamped specimens were mounted in a materials-testing machine (Fig. 2) and could be tested in three different ways.

First, the clavicle was lifted from a standard position at the lateral end of the bone (FC = 100 N) to simulate the weight of the arm. Second, elevation of the sternal clavicle was performed (FE = 50 N) while the vertical guidance was loosened. Third, rotation of the clavicle was carried out (rotational moment FR = 100 Ncm). Rotation and elevation of the clavicle occur naturally during abduction of the arm [6, 9].

The implants tested in this study are shown in Fig. 3. All of the implants were mounted onto each of the plastic models and

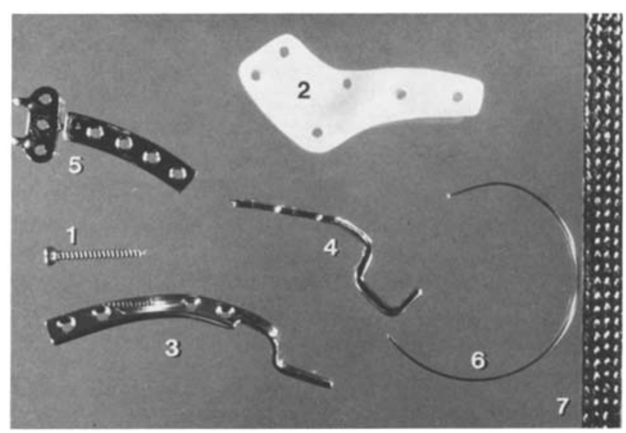

Fig. 3. Surgical implants tested: *1*, Bosworth screw; *2*, Streli plate; *3*, Balser plate; *4*, Wolter plate; *5*, Rahmanzadeh plate; *6*, cerclage (to combine with K-wires); *7*, carbon-fiber ligament

onto six cadaveric specimens. The following measurements were made:

1. The craniocaudal dislocation of the AC joint was obtained and is referred to here as the "acromioclavicular step" (AC step). This was calculated from the difference of the signals of two inductive displacement pickups which were placed at defined locations on both sides of the joint (Fig. 4).
2. The increase of the distance between the coracoid process and the clavicle (referred to as the "CC step") was measured.
3. The stiffness of the implants against the rotation moment of the clavicle was determined.
4. The increasing strain in the two parts of the coracoclavicular ligament (trapezoid part and conoid part) was measured

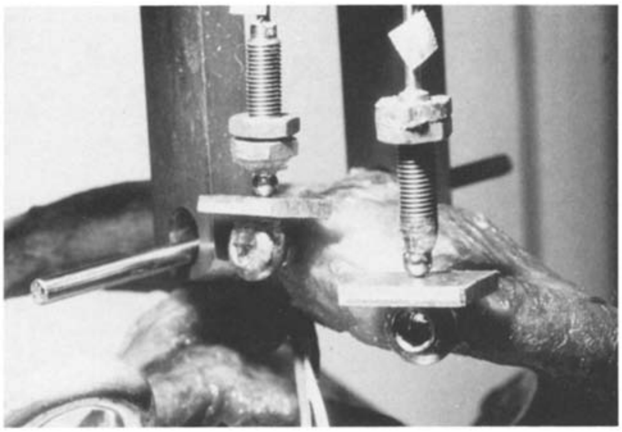

Fig. 4. AC step measurement system. Two displacement pick-ups give signals of the deformation from the lateral clavicle and the acromion

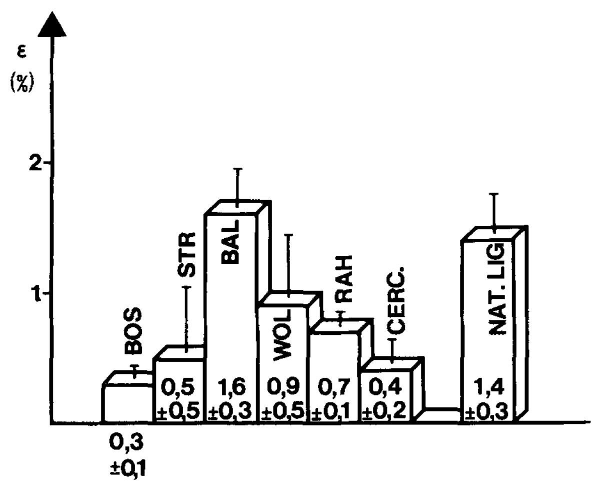

Fig. 5. Strain in the conoid ligament during cranial force (AC step). Lowest strain (ε_2) for Bosworth screw and cerclage/K-wires

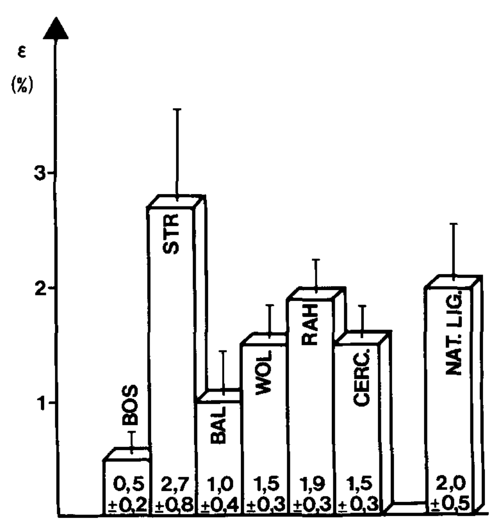

Fig. 6. Strain in the conoid ligament during elevation (CC step). Lowest protection afforded by the soft Streli

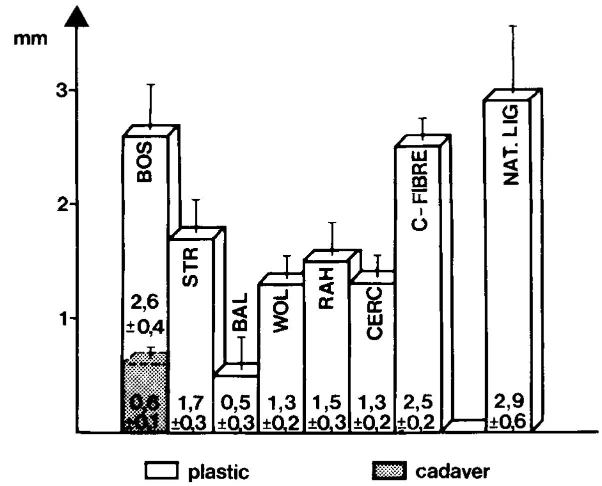

Fig. 7. AC step. All implants were able to prevent the joint from major dislocation. Results shown were obtained with plastic models. The differing value for the Bosworth screw in cadaveric joints is shaded for comparison

using specially developed omega-shaped strain gauges which were sutured to the ligaments [3].

5. The length of the coracoclavicular ligaments was determined. Measurements of the strain were carried out in the intact coracoclavicular ligaments of the cadaveric specimens and then repeated following the attachment of the various implants. The ligaments were severed and the AC step was measured. The ligaments were sutured with Polydioxanon sutures in the conventional manner and the measurements repeated. Strain and stress curves were plotted until failure of the sutures occurred. Carbon-fiber ligaments were then used to replace the severed ligaments and the measurements were repeated. The plastic models were used to obtain measurements of the AC step, the CC step, and the stiffness of the joint following application of the implants.

Results

The mean length of the trapezoid ligament was 16.2 mm, and the average length of the conoid ligament was 14.7 mm. The values for the strain in the conoid ligament due to lifting cranially at the lateral clavicle are shown in Fig. 5; the values for elevation of the medial clavicle (mean ± SEM) are shown in Fig. 6. The results of the acromioclavicular dislocation (AC step) are plotted in Fig. 7. The increase of the coracoclavicular distance (CC step) is shown in Fig. 8. The rotational stiffness values of the implants are summarized in Fig. 9.

The mean ultimante tensile force for the cut and resutured ligaments and capsules while performing elevation of the medial clavicle was 48.6 N ± 5.5 N (SEM). At the time of rupture, an increase of 8.8 mm ± 0.8 mm in the coracoclavicular distance had occurred.

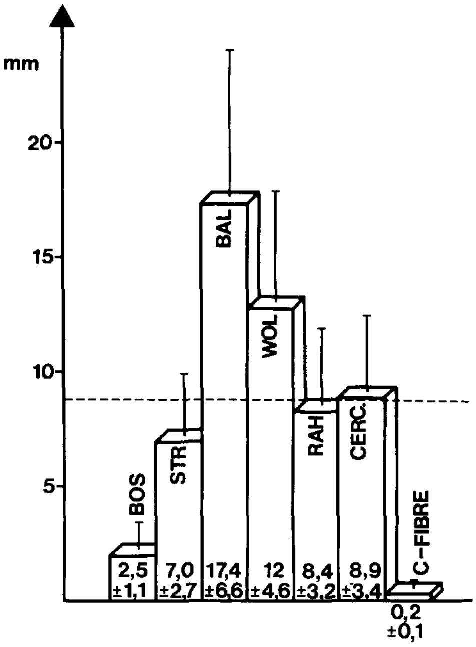

Fig. 8. CC step. The dotted line shows the ultimate tensile force for the cut and resutured ligaments. No protection from dislocation can be given by the Balser and Wolter plates

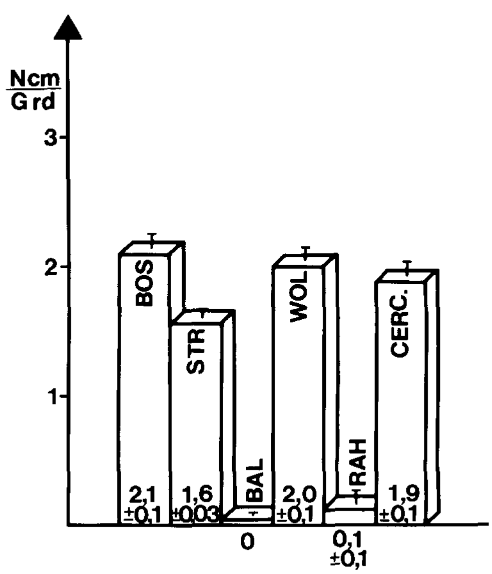

Fig. 9. Rotational stiffness of the implants. High rotational stiffness protects the suture from rupture. Here the Balser and Rahmanzadeh plates failed

Discussion

Plastic models were used for the first part of the experiment because of their independence from soft tissue influences. The standardized size of the specimens better enabled the real effect of the various implants to be studied. For comparison the same measurements were repeated using cadaveric specimens. In addition, the strain in the coracoclavicular ligaments could be measured to obtain further information about the stress in the joints.

Lifting cranially at the lateral clavicle for measurement of the AC step led to a shear stress in the joints and implants. All of the implants were able to prevent the joints from a major dislocation in this test. The step for the Bosworth screw was a lot higher in the plastic models than in the cadaveric specimens due to the softer nature of the plastic coracoid process. The difference in the results for the Balser plate between plastic and natural joints must be explained by the frequent "slipping off" of the plate hook below the human acromion.

Strain measurements in the conoid ligament while the lateral clavicle was pulled cranially confirmed the results of the AC step. The normal strain of 1.4% was reduced to 0.9% or more by all of the implants but the Balser plate, which continually slipped along the bone.

Fixation of the acromioclavicular joint with unhindered rotation has been thought to be the advantage of the Balser and Rahmanzadeh plates. Measurements of the rotational stiffness of the implants revealed almost zero for these two plates while the other four implants (no test for the carbon-fiber ligaments was performed) showed a uniform stiffness of about 4 Ncm per grade (Fig. 9). Low rotational stiffness of the protecting implant might be dangerous for the healing coracoclavicular ligaments when abduction of more than 90° is allowed and thus should be avoided.

The strain values of the trapezoid ligaments were not uniform due to differing ligament insertions and different anatomical properties and they are therefore not shown here.

Elevation of the clavicle at the medial end led to a major increase of the coracoclavicular distance

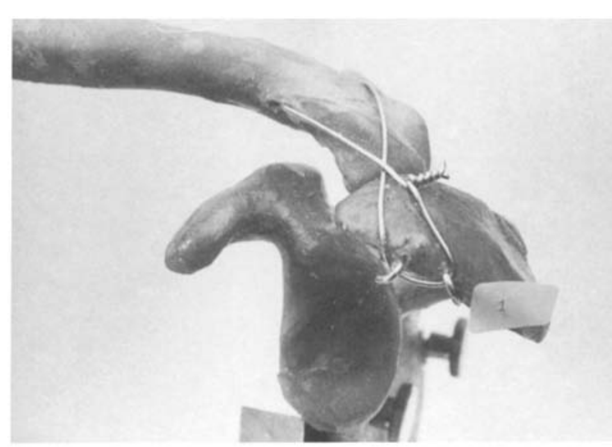

Fig. 10. Cerclage combined with K-wires. Most satisfactory implant in the experiment, shown on a plastic model

using the Balser plate or the Wolter plate, while the Bosworth screw provided a stable fixation. Elevation of the clavicle occurs during arm abduction and causes bending stress for the implant at the position of the AC joint. Therefore, material properties, form, and dimensions of the implants are most important for this position at the joint. The resistance to this bending by the soft Streli plate and the ball-jointed Rahmanzadeh plate was very low, and this led to high strains in the conoid ligaments.

Increasing the coracoclavicular distance more than 8 mm leads to failure of the ligament sutures (Fig. 8). Consequently, implants which allows dislocations of more than 8 mm cannot protect repaired ligaments from redislocation during the healing period, when the same stiffness for intact and sutured ligaments is assumed. Stability of chronically dislocated AC joints can be safely provided by carbon-fiber replacements with respect to the AC and CC steps.

Due to the weak material and the huge dimensions of the Streli plate and to the lack of rotational stability of the Balser and Rahmanzadeh plates, these implants cannot be recommended for temporary stabilization. The Bosworth screw causes a rigid fixation which leads to failure of the screw due to fatigue of the material. With respect to the investigated biomechanical properties, K-wires in combination with a cerclage (Fig. 10) and perhaps the Wolter plate might be the best methods for temporary stabilization of surgically treated acromioclavicular separation.

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