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Biomechanical Analysis of Different Operative Techniques for Complete Acromioclavicular Joint Disruptions

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Abstract

The goal of this study was to evaluate three different operative techniques for acromioclavicular joint fixation: trans-articular K-wire fixation; ligament reconstruction along with a synthetic augmentation device (LARS®); and coracoclavicular Bosworth screw. Mechanical properties were tested in a cadaver study in order to determine the primary mechanical stability during repetitive passive motion. Eighteen fresh cadavers were used to test a cyclic load (50000 cycles). Secondary joint dislocation and the rate of implant loosening were monitored by standard AP stress X-ray. Metal markers in the coracoid, the acromion, and the lateral clavicle were used to measure the acromioclavicular distance increase (Δ-AC) and the coracoclavicular distance increase (Δ-CC). The range of motion was set on 30–90° of abduction for the first 25000 cycles and then was raised to 60–120°. The least amount of vertical dislocation was seen in the K-wire and the LARS® group (mean Δ-CC 0.3 mm; range: 0–1.3 mm and 1.5 mm; range 0–6.7 mm, respectively). The Bosworth group showed significantly higher dislocation rates (4.2 mm; range 2.3–7.1 mm; $p = 0.005$). This was true especially when the abduction range was extended to a maximum of 120 . The rate of implant loosening in the K-wire group was higher than that in the other two groups. This study shows that the LARS® procedure and the K-wires technique give equal results concerning stability after repetitive passive motion, but with a high rate of implant loosening in the K-wire group. According to our findings, abduction should be limited to 90 after implanting a Bosworth screw in order to prevent loosening or failure of the hardware.

Key words
AC joint · biomechanics · anatomical study

Introduction

Complete acute acromioclavicular joint (AC joint) dislocations can be surgically repaired by trans-articular or extra-articular techniques [27]. Discussion regarding the disadvantages and advantages of the described methods are ongoing. Trans-articular techniques, like transfixation by K-wires, or the use of plates, like the Balser's or Wolter's plate, have been reported to give good primary stability [6, 10, 22]. However, they have the potential of damaging the intra-articular structures of the joint, such as the fibrocartilaginous disc, and have to be removed during a second operative procedure. K-wires have been described to exhibit a high dislocation and breakage rate [3, 13, 23]. Extra-articular techniques, like the use of a transclavicular Bosworth screw, may avoid surgical damage to the intra-articular compartment [4]; however, these implants also show a high rate of implant-related complications, especially if the postoperative rehabilitation protocol is very aggressive [24]. Loop techniques, like the LARS® procedure, represent a non-rigid, extra-articular

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Fig. 1 Representative X-rays for the three compared operative techniques. Metal markers were placed into the coracoid, the acromion, and the lateral clavicle to measure the acromioclavicular (Δ-AC) and coracoclavicular (Δ-CC) distance increases.

fixation of the AC joint [8, 25]. The sutured coracoclavicular and acromioclavicular ligaments are reinforced with a synthetic augmentation device. This technique shows good early functional rehabilitation in clinical practice [7].

The aim of this study was to evaluate the mechanical properties of three techniques that represent extra- and trans-articular fixation principles. During a biomechanical test, both the rate of secondary joint dislocation and potential implant loosening were studied.

Material and Methods

Specimen preparation

Eighteen fresh cadavers were used for this examination (average age 63 years; range 49–81). The cadavers were prepared using a vertical surgical access, immediately lateral to the tip of the coracoid process. The acromioclavicular joint was carefully exposed. The joint capsule and its reinforcing ligaments were dissected. The intra-articular disc was preserved, if present. The coracoclavicular ligaments were exposed by splitting the anterior deltoid fibers and were also dissected. The produced instability was confirmed by the use of an image intensifier. Three metal markers were introduced, into the coracoid, the lateral end of the clavicle, and the acromion, in order to be able to determine corresponding measure points for vertical or horizontal dislocation.

Operative procedures

Three different techniques were evaluated:

- Group A: Intra-articular fixation by K-wires and a tension-band fixation (two parallel 2 mm K-wires and a 1.25 mm cerclage wire in the form of a "figure of eight").
- Group B: Extra-articular fixation by direct suture of the ligaments and augmentation with a synthetic ligament (absorbable braided sutures number 2; LARS® ligament "LAC 30" (LARS®, Arc sur Tille, France) and two titanium interference screws of 5.2 and 15 mm).
- Group C: Extra-articular fixation with a transclavicular screw into the base of the coracoid (Bosworth screw [4]; 6.5 mm steel screw and a washer).

The techniques were assigned randomly, with an equal number (n = 6) of specimens for each operative technique. The implants for groups A and B were introduced according to standard surgical procedures. For group C, the base of the coracoid was exposed. After marking of the dissected coroid and trapezoid parts of the coracoclavicular ligament with braided sutures (Dexon No. 2, Fa, USA), the augmentation device (LARS) was passed around the coracoid using a special shuttle device. Two drill holes were prepared perpendicular to each other to ensure that the inferior entry point of the device was exactly at the origin of the coroid and trapezoid parts of the coracoclavicular ligament. The device to be implanted exactly parallel to the dissected ligaments. After reduction of the joint, the implant was fixed with two titanium interference screws. Finally, the skin was closed by sutures to prevent dehydration. The entire procedure was performed in a cooling unit to slow down the autolytic processes (Fig. **1**).

Testing machine

A custom-made laboratory table was used to hold the specimen. The table was H-shaped to allow unrestricted passive motion of the upper extremity. The testing machine was mounted on a side table that could be rigidly connected to the specimen-holder. The construct allowed only 30° of extension and flexion, but different degrees of abduction, always holding a fixed angle of 60° between minimum and maximum abduction. This was necessary to lead the arm around a circular path to simulate a passive range of motion within the limits set (Fig. **2**).

Fig. 2 The testing maschine.

Testing protocol

At the beginning an AP stress X-ray was taken in order to evaluate implant position and joint congruity ahead of the planned testing procedure. To guarantee reproducible findings, a vertical load of 5 kg was applied for 5 min prior to every X-ray. The testing machine was prepared to perform 25 000 cycles at a range of 30–90° of abduction (15 cycles/min). After obtaining a second stress X-ray, the abduction range was changed to 60–120° for the next 25 000 cycles. A third X-ray concluded the testing.

The radiological analysis was aimed at detecting signs of implant loosening or migration, and secondary joint dislocation. Horizontal displacement was defined as acromioclavicular distance increase (Δ-AC), and vertical displacement as coracoclavicular distance increase (Δ-CC). The distances between the metal markers were measured and the difference between two measurements was noted in millimeters.

Statistics

For statistic analysis, ANOVA was used. A p-value of < 0.05 was considered to be statistically significant.

Results

The three techniques showed different mechanical behaviors depending on the applied range of motion. After 25 000 cycles with a maximum abduction of 90°, the joints in group A (tension-band wire) and group B (LARS®-technique) proved to be almost as stable as at the beginning of the test (Figs. **3** and **4**). This was observed for the horizontal dislocation (mean Δ-AC 0.7 mm and 0.3 mm, respectively) as well as for the vertical dislocation (mean Δ-CC 2.0 mm and 0.4 mm, respectively). In the group that received the Bosworth screw (group C), there was a markedly higher increase in the mean coracoclavicular distance (mean Δ-CC 2.3 mm).

After 25 000 additional cycles at a maximum abduction of 120°, the least vertical dislocation was found in the group of LARS® procedures (mean Δ-CC 0.3 mm; range: 0–1.3 mm). Group A (tension-band wire) joints showed only minimal loss of horizontal stability (Δ-AC 0.6 mm). The Bosworth screw group had a statistically significant higher dislocation rate in both the horizontal and the vertical plane (Δ-AC 3.1 mm and Δ-CC 4.2 mm, respec-

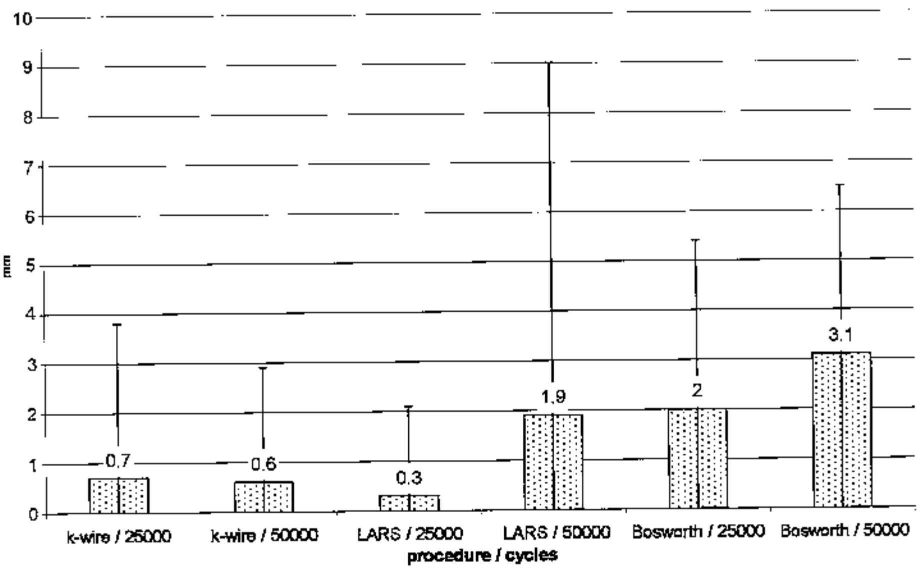

Fig. 3 Mean increase of the acromioclavicular distance (Δ-AC) for all implants after 25 000 and 50 000 load cycles.

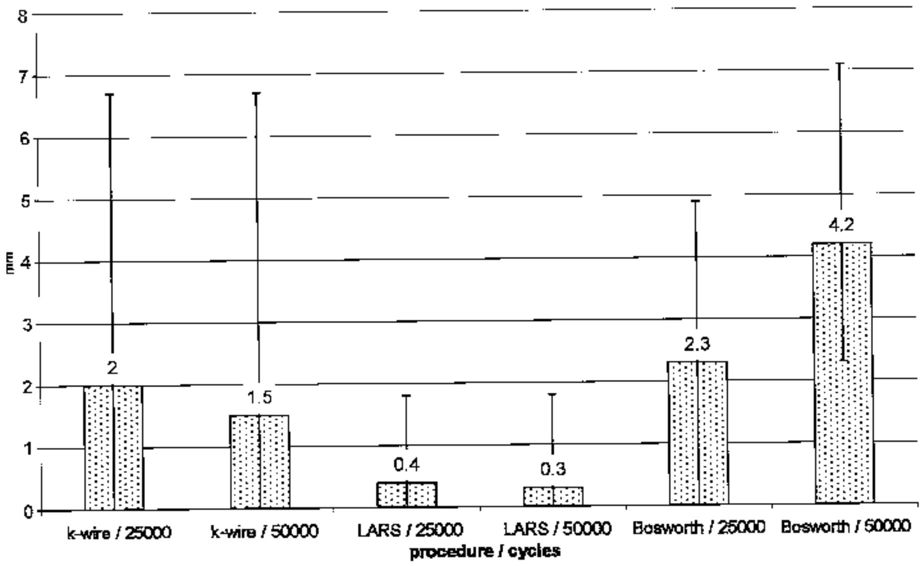

Fig. 4 Mean increase of the coracoclavicular distance (Δ-CC) for all implants. The mean amount of vertical dislocation in group C (Bosworth screw) increased after changing the maximum abduction from 90 to 120°.

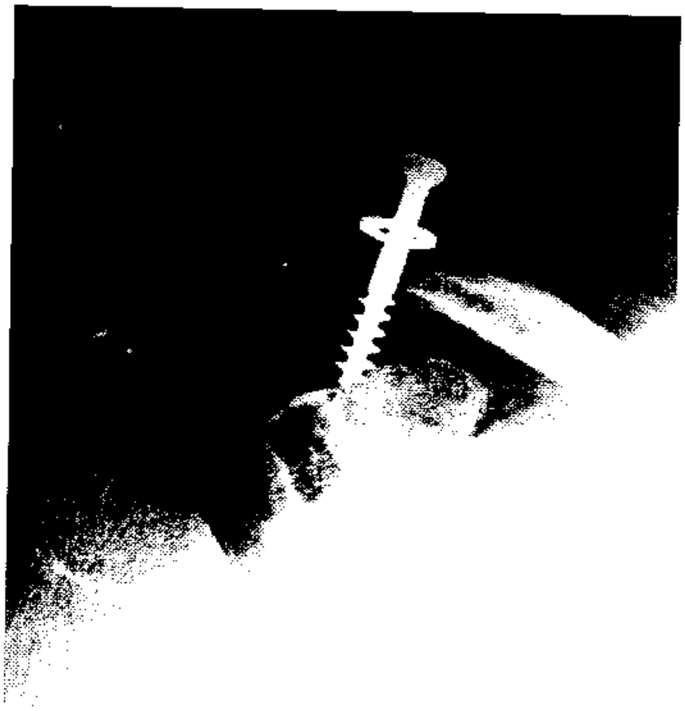

Fig. 5 Dislocated Bosworth screw.

tively; p = 0.005). In this group, a total implant failure was observed (complete screw dislocation; Fig. **5**). Nonetheless, even after exclusion of this case, the group showed significantly poorer results compared to those obtained with the other two techniques (Δ-AC 2.4 mm and Δ-CC 3.9 mm, respectively: p = 0.017). The mean Δ-CC in group C (Bosworth screw) was significantly increased after the passive range of motion had been extended to 120° of abduction (Fig. **2** and Tables **1** and **2**).

The effects of continuous passive motion on the rate of implant loosening were also compared. After 25 000 cycles, two out of six screws in the Bosworth group had migrated more than 6 mm. Also, in the tension-band group, three out of six K-wires had migrated up to 18.0 mm. In the LARS® group, no migration of the screws was observed. After the second 25 000 cycles at 120° of abduction, three out of six Bosworth screws showed a displacement. In five out of six joints, the K-wire had become displaced. In contrast, only one of the screws in the LARS® group showed a measurable displacement (1.3 mm).

Discussion

The anatomic inclination of the acromioclavicular joint shows great interindividual variability. Renfree described "over-riding" and "under-riding" types of clavicles [26]. The joint capsule and its reinforcing ligaments act in combination with the perpendicularly oriented conoid and trapezoid parts of the coracoclavicular ligaments as the main stabilizers of the AC joint. Additionally, they are responsible for longitudinal rotation of the clavicle during active motion of the upper extremity [9, 26, 28]. The role of the intra-articular disc is still unclear. As a fibrocartilaginous structure with limited blood supply it can easily be damaged without the potential of healing. This is likely during primary trauma as well as due to surgical manipulation during joint transfixation with metal implants [31].

During the planning and building of the motion device, the aim was to produce mechanical conditions similar to those occurring in postoperative motion under physiotherapy. Therefore, the upper extremity was guided around a circular path in repetitive passive motion. Linear loading with either a horizontal or vertical orientation of the AC joint would fail to produce forces comparable to those during postoperative training [18, 24]. Additionally complete cadavers were used in order to conserve all passive stabilizers (attaching tendons and ligaments) that support the AC and coracoclavicular ligaments. This allowed correct application of the forces and similar to active motion in vivo.

The vast majority of operative techniques for acute AC joint separations involve rigidly fixating the clavicula relatively to the acromion by a metal or synthetic implant [18]. The aim of every method is to secure reduction until the torn ligaments are healed. In contrast, only a few authors have recommended direct suturing of the coracoclavicular ligaments [14, 16]. Explicit recommendations for reconstruction of the torn ligaments, especially the superior AC ligament, are found only in a very limited number of papers [12, 22]. Prior biomechanical studies showed that abduction of more than 90° has a significant stress-increasing effect on the coracoclavicular screws [29, 31]. The mechanical properties

Table **1** Horizontal distance increase (Δ-AC) for the three different techniques: minimum (min), maximum (max) and average values (mean) after 25 000 and 50 000 cycles

Δ-AC	*25 000*	*50 000*	*cycles*
K-wire	0.7	0.6	mean
	0.0	0.0	min
	3.7	3.7	max
LARS®	0.3	1.9	mean
	0.0	0.0	min
	1.2	9.0	max
Bosworth	2.0	3.1	mean
	0.0	0.0	min
	5.4	6.5	max

Table **2** Vertical distance (Δ-CC) increase for the three different techniques: minimum (min), maximum (max) and average values (mean) after 25 000 and 50 000 cycles

Δ-CC	*25 000*	*50 000*	*cycles*
K-wire	2.0	1.5	mean
	0.0	0.0	min
	6.7	6.7	max
LARS®	0.4	0.3	mean
	0.0	0.0	min
	1.8	1.8	max
Bosworth	2.3	4.2	mean
	0.0	2.3	min
	4.9	7.1	max

of the specific implant evidently dictate the extent of postoperative rehabilitation. This is the main reason that active motion during physiotherapy is restricted to the horizontal level for 6 weeks postoperatively [10, 27]. Too early active motion bears the risk of loosening the anatomic reduction. Therefore an operative procedure is required that secures the primary stability until ligament healing is achieved. This also requires proper mechanical stability in order to allow early functional rehabilitation [15].

In the present study, commonly used techniques (Bosworth screw and joint transfixation with K-wires and a "figure of eight") were compared with each other and with the LARS® procedure. The latter contrasts rigid fixation with metal implants and represents a dynamic fixation that seems to allow early functional rehabilitation without implant loosening.

The K-wire technique is reported to be a very rigid and stable method [1, 27]. But during the postoperative course several types of implant failures, such as pin migration, bending or breakage and subsequent soft-tissue irritation or infection [20]. There are even reports of life-threatening pin dislocation into the lung [21].

Coracoclavicular screw fixation was introduced by Bosworth in 1941 [4]. It is commonly used in both acute and chronic cases in combination with ligament transposition [2, 19, 30]. Nevertheless, the procedure is associated with a large number of surgical complications and pitfalls. Incorrect positioning of the drill holes may lead to either fixation in diastasis or to a pathologic increase of the intra-articular pressure [12, 31]. Postoperative complications include implant loosening and secondary joint subluxation with or without clinical symptoms [12].

Ligament reconstruction by suture with synthetic augmentation is rarely described in the literature. The use of a Dacron prosthesis showed good primary results but secondary loosening due to implant elongation during further follow up [17]. Also, aseptic foreign body reactions to the implant have been reported [5]. The use of resorbable implants, like PDS bands, has yielded good early functional results and the possibility of early postoperative motion [11].

It is clear that biomechanical studies provide information only about primary mechanical stability and do not allow evaluation of the clinical reliability of a tested operative technique. Nevertheless, knowledge of the mechanical properties of the various implants leads directly to understanding the limits of postoperative functional rehabilitation for a patient with a specific implant.

The data show that the LARS® procedure and the K-wire technique gave similar results concerning stability after repetitive passive motion, but there was a high rate of implant loosening in the wire group. According to our findings, abduction should be limited to 90° after implanting a Bosworth screw in order to prevent loosening or failure of the hardware.

Conclusion

Trans-articular K-wire fixation of the AC joint combined with tension-band cerclage provides good mechanical resistance against secondary joint dislocation during passive motion, but with a high rate of implant migration. The Bosworth technique has poorer mechanical properties and has a high rate of secondary dislocation, especially after increasing abduction above the horizontal level. Repair of the ligaments along with the use of a synthetic augmentation device (LARS®) results in excellent mechanical stability. Currently, from a biomechanical point of view, this procedure seems to work in clinical practice, even under aggressive postoperative rehabilitation protocols.

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