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Value of additional acromioclavicular cerclage for horizontal stability in complete acromioclavicular separation: a biomechanical study

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Abstract

Purpose To evaluate whether isolated anatomical coracoclavicular (CC) ligament reconstruction with two suture-button devices provides equal horizontal acromioclavicular joint (ACJ) stability compared to additional ACJ suture tape cerclage.

Methods A servohydraulic testing machine was used to assess horizontal ACJ translation in 12 fresh-frozen human shoulders during 5,000 cycles of dynamic anteroposterior directed loading (70 N). Horizontal ACJ stability was assessed for native specimen ($n = 6$) and compared to specimen with dissected AC ligaments but intact CC ligaments ($n = 6$). After complete AC/CC dissection, an anatomical CC reconstruction was performed with two suture-button devices ($n = 6$) and compared to the additional ACJ suture tape cerclage ($n = 6$).

Results Native specimen showed an mean horizontal amplitude of 10.8 mm [standard deviation (SD) 3.29]. After 5,000 cycles of horizontal loading (70 N), mean amplitude increased by 1.5 mm (SD 0.75, $p = 0.005$). Specimen with dissected AC ligaments started at an mean amplitude of 14.1 mm (SD 4.11), which was increased by 0.9 mm (SD 0.56, n.s.) after loading. Initially, amplitude of specimen with anatomical CC reconstruction was 13.2 mm (SD 2.75), which increased by 2.9 mm (SD 1.45, $p = 0.001$) after loading. The specimen with additional AC cerclage initially showed an amplitude of 10.6 mm (SD 2.35). After loading, translation was increased by 3.0 mm (SD 0.97, $p = 0.001$). There was no failure of any surgical reconstruction in the tests.

Conclusion The results of this study suggest that only combined AC and CC reconstruction can adequately re-establish physiological horizontal ACJ stability. Therefore, it is likely that a combined surgical procedure with double suture-button devices and AC suture tape cerclage can adequately re-establish horizontal AC joint stability in case of an acute injury (≥type Rockwood IV and may allow superior clinical outcomes for patients, especially if early functional rehabilitation is intended).

Keywords Acromioclavicular joint · Acute separation · Rockwood classification · Coracoclavicular ligaments · Acromioclavicular ligaments · Horizontal instability

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Introduction

The balance of mobility and joint stability is a significant challenge for surgical treatment of acromioclavicular joint (ACJ) separations. The individual anatomy of the ACJ with its wide variety in 3D intra-articular angle, range of motion, strength, and joint congruity complicates the effort to anatomically restore the ACJ after complete traumatic separation [13]. At present, there is a wide consensus on nonoperative treatment for acute Rockwood types I and II [23] and surgical treatment of Rockwood types IV–VI injuries [14, 26]. It still remains controversial whether Rockwood type III lesions require surgical reconstruction or not [16, 18]. There is no clear evidence for either treatment to result in superior outcomes [1].

Especially, the distinct functional anatomy of the two coracoclavicular (CC) ligaments (conoid and trapezoid ligament) has led the focus to anatomically reconstruct these structures for improved function and stability [5, 10, 15, 20]. Techniques to arthroscopically reconstruct the conoid and trapezoid ligament by using suture-button devices have been described [18]. This approach is thought to limit intraoperative morbidity and—in contrast to open procedures—allows diagnosis and treatment of concomitant intra-articular pathologies (e.g. SLAP lesions) [25]. As this approach alone does not directly address the disrupted AC ligament complex, horizontal instability due to insufficient healing could result. While there is broad consensus that vertical reposition and stability are attributed to the CC ligaments [29], horizontal stability is mainly contributed to the ACJ complex [8]. With the isolated reconstruction of the CC ligaments, a very protective post-operative protocol may be needed to achieve sustained long-term horizontal ACJ stability. Since it has been shown clinically that horizontal instability of the ACJ may result in severe chronic pain and functional shoulder impairment [22], there is a raising focus on the relevance of specific techniques thought to improve horizontal stability (e.g. ACJ cerclage) [24].

To our knowledge, there is no data on the effect of dynamic loading on horizontal ACJ stability after anatomical reconstruction of the CC ligaments versus an additional stabilization of the ACJ using a modified figure of eight suture cerclage. Thus, the purpose of this study was to biomechanically investigate horizontal stability of these surgical techniques during extensive bidirectional anteroposterior dynamic loading. This new set-up simulates a more realistic approach to study cyclic physiological horizontal loading (e.g. repetitive range-of-motion during rehabilitation) of the ACJ compared to conventional load-to-failure experiments.

It was hypothesized that isolated anatomical CC ligament reconstruction provides equal horizontal ACJ stability if compared to native shoulders with intact AC and CC ligaments. Secondarily the authors hypothesized that an additional ACJ cerclage provides no additional horizontal ACJ stability compared to the isolated CC ligaments reconstruction.

To our knowledge, this is the first study that uses—extensive—bidirectional anterior–posterior dynamic loading in the horizontal plane of the AC joint.

Materials and methods

Specimen preparation

A sample size of twelve fresh-frozen cadaveric human shoulders (9 right/3 left shoulders, mean age 59 ± 13 years) was used for the study. Each specimen was thawed for 12 h at room temperature for consecutive testing. The specimens were dissected carefully off all soft tissue including the rotator cuff, and the glenohumeral joint was exarticulated. The AC ligaments, the CC ligaments, and the coracoacromial (CA) ligament were left intact.

Any preexisting lesion of the above-mentioned ligamentous restraints (AC, CC, CA ligaments) and severe degenerative changes to the AC joint were ruled out by visual inspection. The exposed biomaterials were kept moist with sterile saline solution throughout the time of testing to prevent tissue dehydration. The scapula and clavicle of each specimen were potted in a custom mould with quick-setting polyurethane cement (RenCast® FC 53 Isocyanate/FC 53 Polyol, Huntsman, Belgium).

Before moulding, the scapula was adjusted within the horizontal and frontal plane to allow for maximal pivoting of the clavicle with tensioned CC ligaments in the horizontal plane. Secondarily, moulding of minimum 2/3 of the clavicle was carried out. For this, the moulded scapula was fixed on an angle table (Fig. 2). The angle table was adjusted until the clavicle was oriented in neutral anatomical position to the scapula. This allowed for maximal horizontal motion of the clavicle parallel to the ACJ line.

First, the properties of native AC and/or CC ligaments horizontal stability were evaluated. Afterwards, sharp dissection of the AC and CC ligaments was performed, and the specific reconstruction techniques were conducted and finally evaluated for horizontal stability. For that reason, all specimens were randomly distributed to two groups; thus, each group consisted of $n = 6$ specimens. *Group 1* represented native specimens (anatomical AC and CC ligaments), and *group 2* comprised specimens with intact CC complex and released AC capsule-ligament complex. These two groups were used to investigate the anatomical restrain of the AC and CC ligaments under bidirectional dynamical horizontal loading (control). After the baseline tests, all AC ligaments were dissected with a scalpel and the same specimens were randomly distributed to two reconstruction groups. In *group 3*, an anatomical CC reconstruction was performed using two suture-button devices. In *group 4*, additional AC reconstruction was

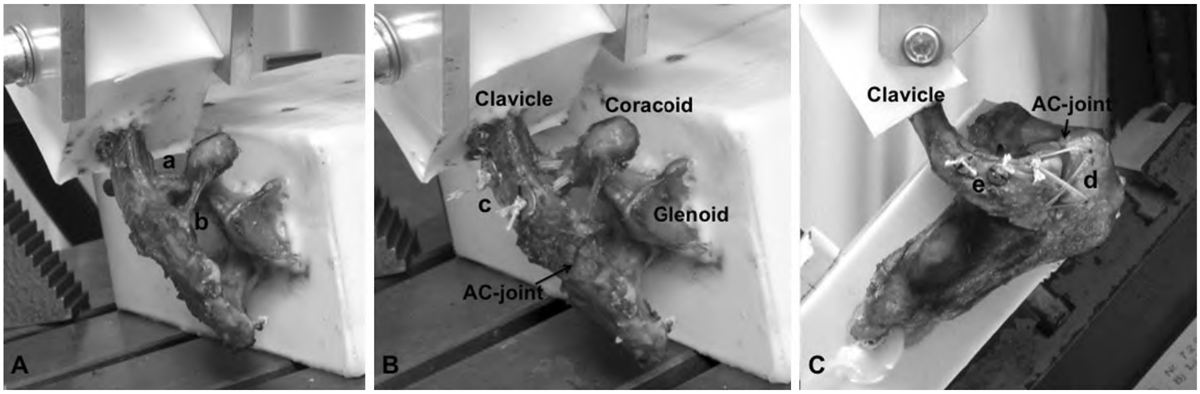

Fig. 1 Specimen (*right side*) mounted into the servohydraulic testing system. **a** Native specimen (group 1) with anatomical Ligg. conoideum (*a*) and trapezoideum (*b*). **b** After CC-/AC-Ligg.-dissection and CC reconstruction (group 3) with two anatomically implanted suture-button systems (*c* TightRope, Arthrex, Naples, FL, USA). **c** Specimen in axial view after anatomical CC-Ligg. reconstruction (*e* TightRope, Arthrex, Naples, FL, USA) and suture tape AC-cerclage (*d* FiberTape, Arthrex, Naples, FL, USA) (group 4)

performed using a suture tape cerclage in a modified figure of eight configuration.

Reconstruction techniques

Group 3

The ACJ was anatomically reduced, and reconstruction was performed in neutral testing position with the specimen mounted into the servohydraulic testing machine.

As described by Walz et al. [27], an anatomical CC ligament reconstruction with two suture-button devices (TightRope, Arthrex, Naples, FL, USA) was performed using a standard AC drill guide (Arthrex, Naples, FL, USA). A 2.4-mm guide wire was drilled through the centre of the clavicle, about 45 mm medial from the lateral clavicular edge, perforating the base of the coracoid posteriorly, about 5 mm lateral to the medial border (conoidal position). A second drill guide wire (trapezoidal position) was placed about 25 mm medial to the lateral clavicular edge. In the coracoid, the wire was positioned 10 mm anterior to the conoidal wire and 5 mm medial to the lateral border of the coracoid. Both guide wires were over-reamed with a 4.0-mm cannulated drill. Subsequently, the suture-button devices were pulled in with shuttle wires. After flipping the inferior buttons, the free limbs of the sutures were tightened over the two clavicular buttons and tied to complete the reposition (Fig. 1b). According to Rios et al. [17], this technique and positioning of the suture-button devices may re-establish the anatomical properties of the CC ligaments.

Group 4

The anatomical CC ligament reconstruction was performed as described above in the specimens of group 3. In addition, the ACJ were stabilized in a modified figure of eight configuration suture tape cerclage (FiberTape, Arthrex, Naples, FL, USA; Fig. 1c). Two vertical 2.4-mm holes were drilled into the acromion, located in line with the anterior and posterior margin of the ACJ, and a 2.4-mm hole was drilled in anterior–posterior direction through the lateral clavicle, about 1.5 cm medial to the medial ACJ line. The suture tape was shuttled through the acromial tunnels using a passing wire as an "U" under the acromion. The longer posterior free limb of the tape was crossed towards anterior over the ACJ and passed through the clavicular tunnel to posterior. Now, the anterior acromial branch was crossed over the ACJ and passed through the clavicular tunnel from posterior towards anterior. Finally, the cerclage was stabilized with a frame running parallel to the anterior and posterior margin of the ACJ. After the longer end was shuttled through the two acromial tunnels in the same way as the first "U", the reconstruction was completed by knotting the tape anterior to the clavicle (Fig. 1c).

Biomechanical testing

To evaluate the main outcome measure of total maximum mean amplitude of horizontal translation [mm], each specimen was mounted in a servohydraulic testing machine (Zwick/Roell HC 10, ±10 kN maximum force, Zwick GmbH & Co KG, Ulm, Germany) with the potted scapula fixed to an angle table which was attached to the base plate of the testing system. The potted clavicle was connected to an adjustable suspension device with the force sensor (Modell 1010-AF, ±2 kN maximum load, Huppert Messtechnik GmbH, Herrenberg, Germany) and the servohydraulic cylinder of the device (Figs. 1, 2).

Position measurement of the testing machine (Zwick/Roell HC10) was carried out using a LVDT sensor (RDP

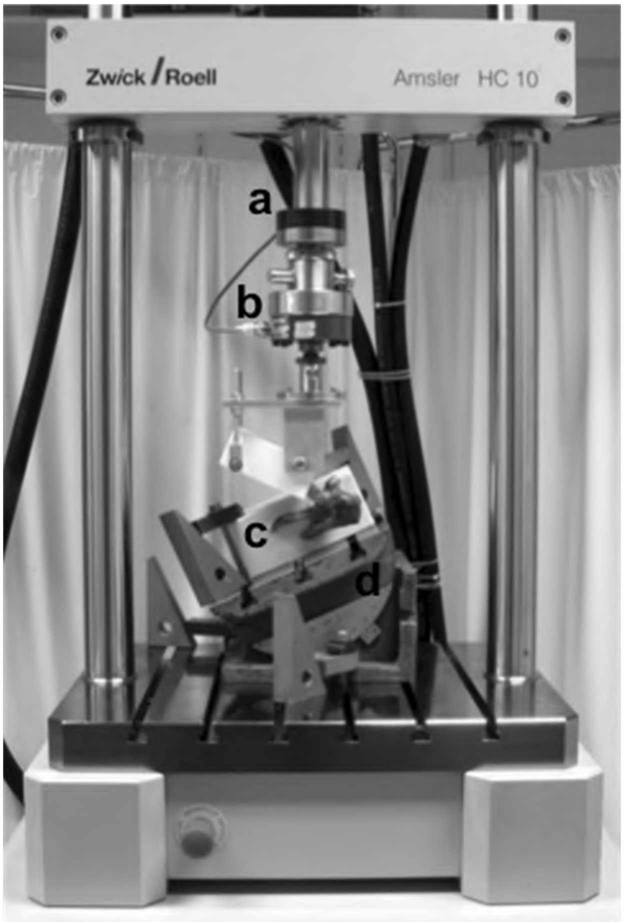

Fig. 2 Test set-up of the specimen mounted into the servohydraulic testing machine. *a* servohydraulic cylinder, *b* force sensor, *c* moulded specimen with adjustable clavicle suspension device

192028, RDP Electronics Ltd, Wolverhampton, United Kingdom) with a measurement accuracy of 0.20 µm. In general, the testing machine presents an accuracy class of ±0.5 %, which represents for the present study an absolute resolution between 2.5 and 100 µm.

The software of the servohydraulic testing system (testXpert Research Dynamic Sequencer, Zwick GmbH & Co KG, Ulm, Germany) was configured to start from the predefined neutral position (max. +4 N load) after preconditioning the specimen with 50 cycles of an anterior and posterior-directed force with 70 N at a frequency of 1 Hz. Subsequently, the software was set to run 5,000 cycles of anterior- and posterior-directed loads with 70 N at 1 Hz, resulting in 10,000 stresses and strains. To outrule bias of clavicular and coracoidal bending and resistance to flexural strength, the applied force of 70 N was chosen according to the study by Costic et al. [4] and Lee et al. [10]. For each test, the combined anterior and posterior translation [total maximum mean amplitude (mm)] after preconditioning (50 cycles) was used as reference value to determine any increase in the amplitude after 5,000 cycles [total maximum mean amplitude; total maximum mean change (mm)]. Secondarily, maximum mean anterior and posterior translation (mm) was recorded. To facilitate data collection, the maximal singular cyclic translation within a block of 50 cycles was recorded.

In summary, this set-up represents a novel protocol for dynamic bidirectional horizontal ACJ stability evaluation.

IRB approval was obtained by the institutional ethics committee (Faculty of Medicine, Technische Universitaet Muenchen, ID number: 5431/12).

Statistical analysis

Statistical analysis was done using SPSS software package (Version 20, SPSS Inc., Chicago, IL, USA). All data are reported as mean ± standard deviation (SD). The level of significance was set to 0.05.

Two-sided level of significance of 5 % was used. ANOVA was used for global and Tukey's test for pairwise comparison.

Results

During the entire testing, there was no failure of any reconstruction (e.g. knot suture-button device, cerclage failure, or fracture).

Group 1: native specimens

After 50 cycles of preconditioning, maximum mean amplitude reached 10.8 mm (SD 3.29) and increased to 12.3 mm (SD 3.31) after 5,000 cycles (see Fig. 3). Thus, under repetitive anteroposterior directed loading, mean amplitude increased significantly by 1.5 mm (SD 0.75, $p = 0.005$).

Maximal difference of mean posterior and anterior translation increased significantly by 0.9 mm (SD 0.72, $p = 0.029$), respectively, and by 0.6 mm (SD 0.27, $p = 0.002$; see Fig. 4).

Group 2: native specimens with dissected AC ligaments

After preconditioning maximum mean amplitude was 14.1 mm (SD 4.11), following extensive dynamic loading, it increased to 15.0 mm (SD 4.34) (see Fig. 3). Thus, this group showed an increase of 0.9 mm (SD 0.56, n.s.).

Maximal difference between mean posterior and anterior translation increased significantly by 0.4 mm (SD 0.2, $p = 0.007$), respectively, and by 0.5 mm (SD 0.47, $p = 0.05$; see Fig. 4).

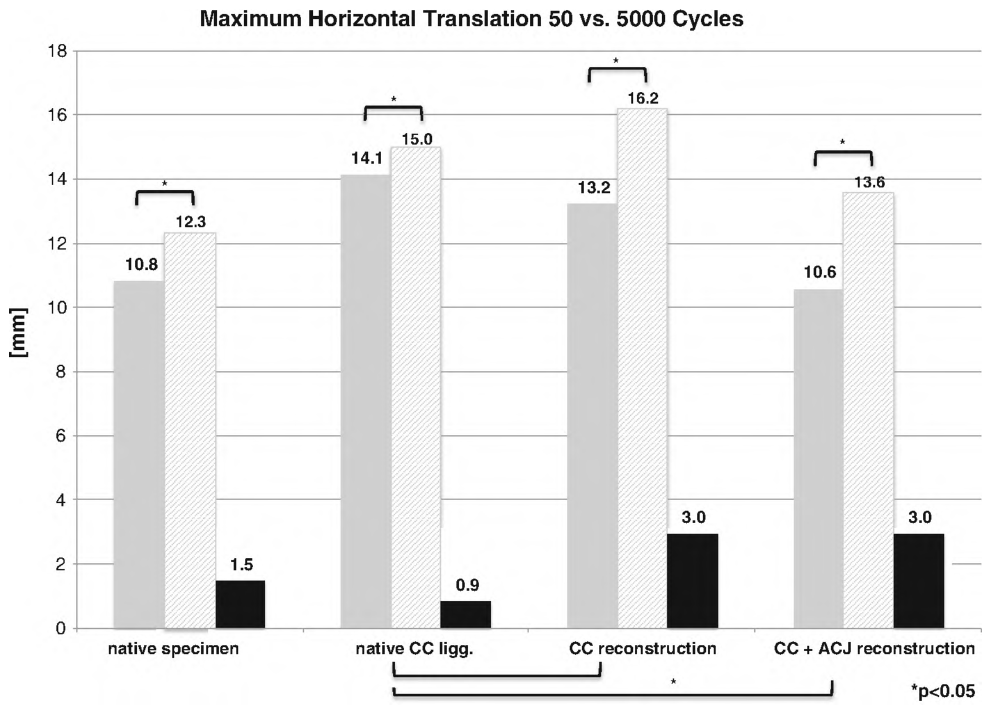

Fig. 3 Maximum mean anteroposterior translation and change of translation (*black bar*) after initial preconditioning loading (50 cycles; *grey bar*) and 5,000 cycles (*grey-striped bar*) of dynamic bidirectional horizontal loading (70 N)

Group 3: isolated CC reconstruction

Initially, maximum mean amplitude of the specimens with CC ligament reconstruction using two anatomically positioned suture-button devices was 13.2 mm (SD 2.75). After repetitive loading, it increased to 16.2 mm (SD 2.62). The increase by 2.9 mm (SD 1.45, $p = 0.004$) was significant (see Fig. 3).

Maximal difference between mean posterior and anterior translation increased significantly by 1.2 mm (SD 0.38, $p = 0.001$), respectively, and by 1.7 mm (SD 1.13, $p = 0.013$; see Fig. 4).

Group 4: combined CC and AC reconstruction

After preconditioning, specimens who underwent anatomical CC ligament reconstruction and additional suture tape ACJ cerclage showed maximum mean amplitude of 10.6 mm (SD 2.35) that increased to 13.6 mm (SD 3.12). The increase by 3.0 mm (SD 0.97, $p = 0.001$) was significant (see Fig. 3).

Maximal difference between mean posterior and anterior translation each increased by 1.5 mm significantly (SD 0.5/0.54, each $p = 0.001$; see Fig. 4).

Comparison between groups

There was a significant difference in maximum mean posterior translation of *group 1* versus *group 2* (initial −3.6 mm, $p = 0.004$; final −3.1 mm, $p = 0.14$) and maximum mean difference in amplitude increase between *group 2* versus *group 3* (mean −2.1 mm, SE 0.57; $p = 0.008$) and *group 2* versus *group 4* (mean −2.1 mm, SE 0.57; $p = 0.007$).

Discussion

The most important finding of the present study is that both the ACJ and the CC ligaments need to be addressed surgically to achieve adequate horizontal stability in the cadaveric study setup.

It is thought to be mandatory for all reconstructive techniques to restore the physiological three-dimensional position and restraining forces of the ACJ. Multiple surgical techniques have been proposed to address separations of the ACJ [1]. Recently, there is a trend to take dynamic horizontal ACJ instability into account when indicating surgical treatment. There is rising clinical evidence that persistent post-operative horizontal ACJ stability is associated with inferior clinical outcomes [22].

Several biomechanical studies are published on ACJ stability of different reconstructive techniques [2–4, 6, 11, 12, 14, 27, 30]. In general, these studies are based on a load-to-failure protocol. Most of these studies focus on superior stability [3, 4, 11, 28]. Only few authors investigated on horizontal stability [6, 9, 30]. Concerning in vivo findings,

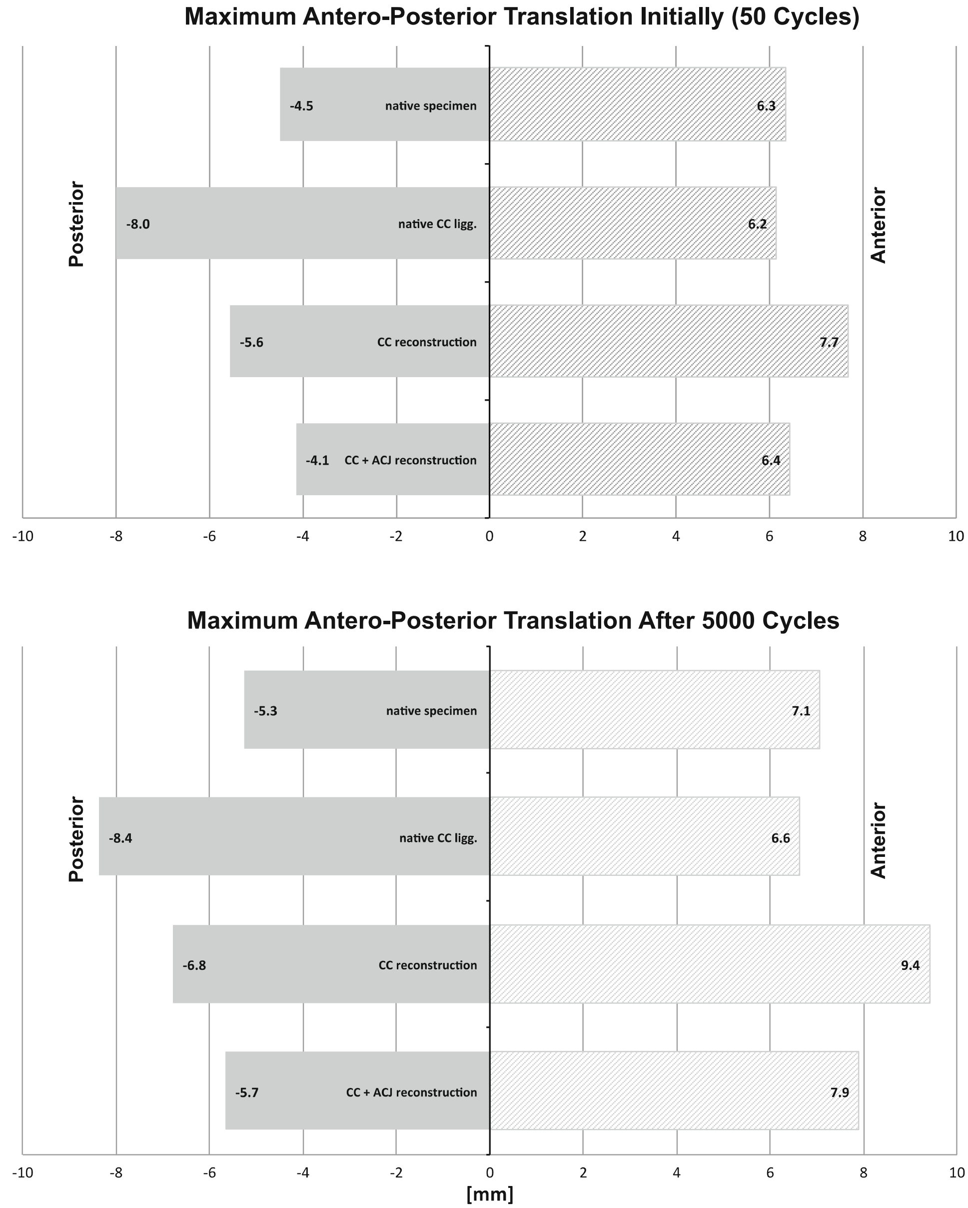

Fig. 4 Maximum mean anterior (*grey-striped bar*) and posterior (*grey bar*) translation initially (50 cycles) and after 5,000 cycles of horizontal dynamic loading (70 N)

there is MRI data by Sahara et al. [19] describing an anteroposterior translation of 1.9 mm posterior and 1.6 mm anterior during abduction in healthy male volunteers. Since the set-up and forces used in these studies differ significantly, comparison of the results may be questionable. Besides, there is no study incorporating bidirectional (anterior and posterior) alternating and extensive dynamic cyclic loading, and the authors are not aware of any other study using anatomical CC reconstruction and ACJ suture tape cerclage. Therefore, the purpose of this study was to biomechanically analyse the primary dynamic horizontal stability of an arthroscopic technique for anatomical CC ligaments reconstruction in comparison with a combined procedure with an additional ACJ suture tape cerclage. For this reason, a novel standardized protocol to evaluate dynamic horizontal AC joint stability was established. In contrast to other studies (e.g. Lee et al. [10]), this approach nullified pull and pressure forces within the joint by directing the load force parallel to the AC joint line. This study focused on extensive repetitive loading, which may best imitate physiological stress of the early post-operative rehabilitation phase. There is good evidence of vertical and horizontal maximum load-to-failure parameters of physiological and reconstructed specimens [4, 6, 9], but this may not explain loss of ACJ reduction in all clinical cases. Our approach may therefore help in finding reasons for early failure after surgery without a history of trauma as described in several clinical studies [21, 22].

The results of native AC/CC ligaments (group 1) versus native CC with dissected AC ligaments (group 2) showed no significant differences in the maximum mean amplitude of horizontal translation before and after extensive dynamic cyclic loading. This finding may be explained by the fact that the CC ligaments are stronger than the ACJ complex. Since translation after preconditioning of the native specimens was smaller, the authors hypothesize that the majority of horizontal resistance was build up by the ACJ complex, leaving the CC ligaments not totally loaded. Thus, the overall bearing structure in native specimens is weaker and allows for a greater elongation during extensive dynamic loading. These findings are in accordance with preliminary anatomical studies published by Debski et al. [5] and Fukuda et al. [7] showing that the AC ligaments primarily stabilize the ACJ in the anterior–posterior plane. In line with Fukuda et al. using a similarly directed load, our data suggest by a non-significant trend that the AC ligaments play a particular role in posterior stabilization of the lateral clavicle. Thus, after dissection of the ACJ ligaments, translation must increase in order to resist the force of 70 N.

Likewise, comparing the two intervention groups, the isolated CC reconstruction (group 3) showed an increased horizontal translation after preconditioning versus the additional ACJ cerclage (group 4). The authors conclude that the ACJ cerclage must be considered the major time zero resistance to anteroposterior translation.

After extensive loading of the groups, there was a significant increase in anterior–posterior translation of the lateral clavicle in all groups. As for group 1 versus 2, as well as for group 3 versus 4, it must be assumed that especially the ACJ stability was weakened until there was a status, when the increased force absorption by the CC restraints limited the elongation of the ACJ structures. The higher amplitude increase within the intervention groups may be due to the fact that the reconstruction techniques cannot reach up to biology, e.g. due to slipping within the drill holes and/or a smaller insertion zone compared to the widespread anchorage of the native ligaments. This finding is contrary to the study by Rios et al. [17] that stated re-establishment of the anatomical properties of the CC ligaments after anatomical CC reconstruction. However, none of the AC or CC reconstructions failed by suture breakage or fractures of the bones during testing with extensive cyclic loading. But, since the anterior and posterior excursions of the groups were alike, the intervention groups are considered to resemble anatomical characteristics of horizontal range of motion.

Most importantly, combined CC and ACJ stabilization (group 4) led to significantly increased horizontal ACJ stability compared to isolated CC ligaments reconstruction (group 3). Thus, the authors conclude that only the combined reconstructive approach (group 4) may successfully restrain repetitive anterior–posterior load. The tendency for dynamic wear, as observed in the isolated CC ligament reconstruction group (group 3), may explain early non-traumatic failures, as has been described before [22].

A limitation of this study is that there is no means to evaluate biological factors such as tissue healing and scarring of disrupted ligaments in a biomechanical cadaver study.

Transferring the experimental results to clinical practice, this study supports a combined AC- and CC reconstruction in ACJ separations ≥Rockwood IV, especially if early functional stability is intended. Therefore, the authors promote to surgically address both the CC ligaments and the ACJ in complete ACJ separation.

Conclusion

The specimens undergoing combined surgical reconstruction of the CC ligaments with two suture-button devices and AC joint stabilization with suture tape cerclage showed physiological horizontal AC joint stability during initial cycles.

Over time, dynamic cyclic loading weakened horizontal AC joint stability in all the tested groups significantly. The specimens that underwent combined CC and AC ligaments reconstruction terminated cyclic loading superior to the group with dissected AC ligaments, but reconstructed CC ligaments and were only minimally inferior to native conditions.

Transferring the results to clinical practice, this study is in support of a combined AC- and CC reconstruction in ACJ separations ≥Rockwood IV, especially if early functional stability is intended. Thus, the authors promote a combined CC and ACJ surgical treatment in complete ACJ separation.

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