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***Title:*** **Three-dimensional Deformities of Non-operative Midshaft Clavicle Fractures: A Surface Matching Analysis**

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All authors can confirm that no authors have any conflict of interest to declare.

*Ethical review committee statement*

This study was approved by the Institutional Review Board of our institutions.

**ABSTRACT**

**Objective:** The purpose of this study was to describe the three-dimensional deformities of midshaft clavicle fractures, which had been treated nonoperatively, using computed tomography (CT) surface matching.

**Methods:** Twenty-one patients with unilateral midshaft clavicle fracture, who had been treated nonoperatively, were enrolled and evaluated retrospectively. The three-dimensional deformity of the fractured clavicle was evaluated by CT surface matching. CT scans of 21 age- and sex-matched patients with initial traumatic shoulder dislocation or proximal humeral fracture were enrolled as a control group, and the differences in three-dimensional deformities and lengths of the clavicles between the fracture group and the control group were evaluated. A correlation analysis was also performed between rotational deformities and clavicular length shortening.

**Results**: The affected clavicle showed 1.3 ± 6.9 degrees of downward angular deformity, 2.1 ± 8.0 degrees of anterior angular deformity, and 5.0 ± 4.9 degrees of anterior rotational deformity. Compared with the control group, the fractured clavicle showed larger anterior rotational deformity (*P* = 0.021). Shortening of the clavicle demonstrated negative correlation with anterior axial rotation (R = −0.534, *P* = 0.013), but no correlation was found between clavicular shortening and the other two rotational deformities.

**Conclusion**: In cases of midshaft clavicle fracture, the distal fragment usually rotates anteriorly due to its anatomical relationships. Shortening deformity following clavicle fracture

was reported to change shoulder kinematics, and anterior rotational deformity might adversely affect scapular motion.

**KEY WORDS: clavicle fracture, malunion, three dimensional analysis**

## INTRODUCTION

Fractures of the clavicle are common injuries, and most of them occur in the midshaft.[1, 2] The clinical results of nonoperative treatment of midshaft clavicle fracture have generally been considered favorable.[3-5] With gravity and muscle forces, however, fractured clavicles usually unite in malposition,[6, 7] and the deformity in adults will remain throughout life. Some studies have reported that clavicular malunion following nonoperative treatment often results in unsatisfactory outcomes due to residual symptoms.[8-12] Clavicular length shortening, which can be assessed on radiographs, has been discussed as the only index of clavicular malunion in past literature.[8, 10, 11, 13-15] However, the deformity subsequent to clavicle fracture is a three-dimensional problem,[7] and the angular and rotational deformities of the clavicle are supposed to concur with shortening. Nevertheless, the three-dimensional deformities of clavicular malunion have not been sufficiently evaluated.

We hypothesized that midshaft clavicular fracture usually causes a three-dimensional rotational deformity. Computed tomography (CT) surface matching is a reliable technique that has been used to evaluate deformities in the tibia,[16] humerus,[17] radius,[18, 19] and ulna.[18-20] The purpose of this study was to evaluate the three-dimensional deformities

of the clavicle following nonoperatively treated midshaft clavicle fracture using a CT surface matching technique and to assess the relationships between shortening and rotational deformities of the clavicle.

## PATIENTS AND METHODS

### Subjects

This study was approved by the Institutional Review Board of our hospital. Patients with traumatic isolated midshaft clavicle fracture, which was treated nonoperatively during the period between September 2012 through March 2014 and united successfully on final follow-up radiographs, were retrospectively recruited for this study. Patients younger than 20 years at the time of injury, with concurrent traumatic injuries, with prior injury of the clavicle, or with past surgery of the affected extremity were excluded from this study. In total, 21 patients (13 men and 8 women; mean age, 57.1 ± 15.8 years; age range, 21 to 80 years) with a history of unilateral midshaft clavicle fracture (13 right and 8 left) met the inclusion criteria for this study and were included (fracture group).

Alignment of the shoulder girdle and displacement of midshaft clavicle fracture may change between the upright position during daily activities and the standing position during CT scanning. Thus, we used CT scans of patients with nonoperatively united fractures of the midshaft clavicle. The average period from the injury to CT scanning was 12.6 ± 11.5 months. All of the fractures successfully united, and no patients needed further surgical

intervention due to severe residual symptoms at the time of the investigation. To evaluate three-dimensional malunion of the clavicle, CT scans of the bilateral clavicles were performed with 1-mm thick slices (GE Healthcare HiSpeed NX/i Pro, Amersham, England; or Toshiba Aquilion™ TSX-101A, Tokyo, Japan), and the data were stored in Digital Imaging and Communication in Medicine (DICOM) data format.

As a control group, the CT data of the bilateral shoulders of 21 age- and sex-matched patients (13 men and 8 women; mean age, 58.6 ± 15.5 years; age range, 24 to 81 years) with unilateral shoulder injuries (12 proximal humeral fractures and 9 initial glenohumeral dislocations; 11 right shoulders and 10 left shoulders), which were taken during the same period, were used because these CT data included whole clavicles, and the clavicles were thought to be normal. CT scans had been evaluated for the assessment of the severity of fracture in cases with proximal humeral fractures and for the presence of concomitant fracture in cases with glenohumeral dislocation. All patients had undergone CT examination within 2 weeks after their injuries with 1-mm thick slices.

**Surface matching**

The surfaces of the bilateral clavicles were extracted from the CT DICOM data using three-dimensional visualization software (AVIZO 6.2, Maxnet, Tokyo, Japan). In all patients, surface data of the left clavicle were flipped horizontally to be aligned with the right clavicle. In fracture group, the affected clavicle was divided into proximal and distal ends by removing the fracture union portion. In the control group, the clavicle of the affected side

(proximal humeral fracture or glenohumeral dislocation) was defined as the affected clavicle, and the clavicle of the opposite side was defined as the intact clavicle. Then, the affected clavicle was divided into proximal one-third and distal one-third sections along the long axis of the clavicle, and the middle portion of the clavicle was removed in both groups.

The surfaces of the proximal and distal ends of the affected clavicle were matched with the intact clavicle surface, respectively. We used the iterative closest point algorithm, from the Visualization Toolkit 6.0.0 (Kitware Inc., NY, USA), for the surface matching technique in which point data of the source surface are transferred and rotated toward the point data on another surface by iterative steps to reach to the closest points. Rotation and translation of the source data are collectively described as the rotation matrix. The rotation angles were calculated from this rotation matrix (Fig. 1).

**Clavicular coordinate system**

To describe rotational deformity, the clavicular coordinate system was then defined on the intact clavicle. The long axis of the intact clavicle was determined as the line between the centers of the proximal ends and distal ends pointing toward the right and was defined as the Z-axis. The acromioclavicular (AC) joint line was defined as the line between the anterior and posterior edges of the AC joint surface pointing forward. The Y-axis was the line perpendicular to both the Z-axis and the AC joint line pointing upward. The X-axis was defined as the line perpendicular to both the Y- and Z-axes pointing forward (Fig. 2).

**Three-dimensional deformity of the clavicle**

Rotation angles were calculated from the differences in the rotation matrices, which described rotation and transfer to match the proximal and distal ends of the affected clavicle with the intact clavicle. Rotation around the X-axis was defined as upward/downward angular deformity, rotation around the Y-axis was defined as anterior/posterior angular deformity, and rotation around the Z-axis was defined as anterior/posterior axial rotation (Fig. 3). Rotation around each axis can be described with the use of the Euler/Cardan angle. The Euler rotation sequence “Y-X-Z” was used because this sequence was used to describe AC joint rotation in the International Society of Biomechanics (ISB) recommendation.[21]

The lengths of the bilateral clavicles were measured as the three-dimensional distance between the centers of the proximal joint surface and distal joint surface on reconstructed three-dimensional surface models. The clavicular shortening percentage was calculated as below:

shortening percentage = [(length of intact clavicle – length of affected clavicle) / length of intact clavicle] × 100 (%)

**Statistical Analysis**

For statistical analysis, SPSS Statistics 22.0.0.0 software (IBM, Armonk, NY, USA) was used. The distributions of the values of angular rotation angles and clavicular shortening percentages in the fracture group and the control group were compared using Levene’s test.

After comparing the distributions, the differences in the values of angular rotation angles and clavicular shortening percentages were assessed between the fracture group and the control group using the two-tailed Student's *t*-test with equal variances or Welch's *t*-test with unequal variances. Then, the correlations between the values of clavicular shortening percentages and each rotation angle were evaluated using the Pearson correlation tests. The significance level was set at 0.05 for all analyses.

## RESULTS

### Three-dimensional deformity of the clavicle

The fractured clavicle showed an average 1.3 ± 6.9 degrees of downward angular deformity (range, −13.6 to 11.0 degrees), 2.1 ± 8.0 degrees of anterior angular deformity (range, −8.4 to 17.9 degrees), and 5.0 ± 4.9 degrees of anterior axial rotation (range, −4.7 to 16.9 degrees). In the fracture group, the fractured clavicle demonstrated an average 10.7 ± 8.9 mm of clavicular shortening (range, −3.2 mm to 27.6 mm) with a shortening percentage of 7.6% ± 6.5% (range, −2.5% to 20.2%).

The distributions of the values were significantly larger in the fracture group than in the control group for upward/downward angular deformity ($P = 0.018$), anterior/posterior angular deformity ($P = 0.003$), and shortening percentage of the clavicle ($P < 0.001$). On the other hand, the variances of the two groups were assumed to be equal in the values of anterior/posterior axial rotation of the clavicle ($P = 0.696$).

No significant difference was found between the fracture group and control group in

upward/downward angular deformity (*P* = 0.674) (Fig. 4A) and anterior/posterior angular deformity (*P* = 0.383) (Fig. 4B). However, the fractured clavicle showed significantly greater anterior axial rotation compared with that of the control group (*P* = 0.021) (Fig. 4C). From these results, a post-hoc power analysis was performed for N = 21, and $1-\beta = 0.05$ using a two-sample t-test, and the power was 0.83. Compared with the control group, the fracture group showed a significantly larger shortening percentage of the clavicle ($P < 0.001$) (Fig. 4D).

**Relationships between rotation angles and clavicular shortening**

On regression analysis, upward/downward angular deformity did not show a significant correlation with clavicular shortening (R = 0.176, *P* = 0.445) (Fig. 5A). There was a moderate correlation between anterior/posterior angular deformity and length shortening, however, which was not statistically significant (R = 0.398, *P* = 0.074) (Fig. 5B). Anterior axial rotation of the clavicle negatively correlated with clavicular shortening (R = −0.534, *P* = 0.013) (Fig. 5C).

**DISCUSSION**

Midshaft clavicle fracture usually unites in malposition and some malunion cases result in poor clinical outcomes.[6, 7] Although clavicular length has been evaluated as an index of malunion,[8-11, 13-15, 22] rotational and angular deformities of the clavicle have never been quantified. The present study is the first report describing three-dimensional deformity following midshaft clavicle fractures. Using CT scans of nonoperatively treated clavicle

fracture, three-dimensional rotation of the distal fragment with respect to the proximal fragment was evaluated by a CT surface matching technique, which has been utilized for analyzing deformities in the extremities.[16-20, 23] The present study indicates that midshaft clavicle fracture usually causes shortening and anterior axial rotation of the distal fragment. Equal distributions of the values were assumed, not in upward/downward and anterior/posterior angular deformities, but in anterior/posterior axial rotation. This fact implied that the distal fragment could angulate upwardly or downwardly in the coronal plane and anteriorly or posteriorly in the axial plane, depending on the fracture pattern, but the distal fragment is supposed to uniformly displace with anterior rotation. On the other hand, the fractured clavicle showed negative correlation between clavicular shortening and anterior axial rotation. Thus, the shorter clavicle has less anterior rotational displacement in cases with midshaft clavicle fracture. Our results imply that clavicular shortening is not the only factor associated with the severity of displacement in cases with clavicular fracture.

This study reveals that midshaft clavicle fracture involves anterior axial rotation of the distal fragment in addition to clavicular shortening. The pectoralis major and latissimus dorsi muscles pull the distal fragment medially with resultant shortening of the clavicle.[6] On the other hand, anterior axial rotation of the clavicle is supposed to be caused by traction force of the anterior portion of the deltoid, which attaches on the anterior surface of the distal clavicle.[6] Malunion following midshaft clavicle fracture often leads to residual symptoms such as pain and weakness around the shoulder girdle.[8-11, 13-15, 22] Several clinical studies have

stated that severe clavicular malunion caused scapular dyskinesis, which could result in poor outcomes.[11, 24] In cadaveric studies, clavicular shortening is reported to decrease posterior tilting and internal rotation of the scapula.[25, 26] Decreased scapular posterior tilting of 5-7 degrees could increase subacromial stress and has been shown to be related to various kinds of shoulder disorders.[27-30] Anterior axial rotation of the clavicle could worsen the scapular dyskinesis caused by clavicular shortening, which might also be related to unsatisfactory outcomes.

This study was the first report evaluating three-dimensional deformities of midshaft clavicle fractures. However, there are several limitations. First, we retrospectively enrolled nonoperatively treated clavicle fractures. At the time of injury, we explained the advantages and risks of both surgical and nonoperative treatments, and treatment strategy was decided with informed consents of the patients. Thus, clavicle fractures with severe displacement and in young, active patients in whom surgical intervention would be needed were not included in this study. Our subjects were older than those in past epidemiological studies.[2, 4] The deformity of the clavicle might be larger than our result in cases of severely displaced fractures, and selection bias might exist in this study. Furthermore, it remains unclear whether or not these clavicular deformities were related to the clinical symptoms. Fractured clavicles showed 5-degrees of anterior axial rotational deformity, but our patients did not require further surgical intervention, as there were no severe residual symptoms at the time of examination. This study does not reveal the threshold of the deformity, and further study is

needed. Another limitation was our definition of the clavicular coordinate axes. Several studies referenced thoracic bony landmarks to define the clavicular coordinate axes.[31,32] However, we found that the bony landmarks of the clavicle could be easily detected and radiation exposure to the thorax could be reduced when the scanning area was limited to the clavicle. Thus, the clavicular bony landmarks were referenced to reconstruct the clavicular coordinate axes in the present study. Our clavicular coordinate system has not been validated, but we regarded the system as appropriate. The fractured clavicles consistently showed the characteristics of the deformities of anterior axial rotation and length shortening. Finally,

## CONCLUSION

Three-dimensional deformities of midshaft clavicular fracture were evaluated using a CT surface matching technique. The present study revealed that the fractured clavicles uniformly demonstrated anterior axial rotation in addition to length shortening. The amount of clavicular shortening negatively correlated with anterior axial rotation deformity but not with upward/downward and anterior/posterior angular rotational deformity. In addition to clavicular shortening, rotational deformities of the clavicle potentially affect scapular kinematics.

## FIGURE LEGENDS

Figure 1

Process of surface matching analysis

Surface data of the bilateral clavicles are created from CT DICOM data. The left clavicle is flipped horizontally. The affected clavicle is divided into proximal and distal parts. The proximal and distal surfaces are matched with the intact clavicle surface respectively using a surface matching technique. Rotation angles are calculated from the differences between the rotation matrices which are required to match the proximal fragment($R_{prox}$) and the distal fragment($R_{dist}$) with the intact clavicle.

Figure 2

The clavicular coordinate system is defined in the intact clavicle.

Anterior and posterior edges of the acromioclavicular (AC) joint. AC joint line is determined as the line between the anterior and posterior edges of the AC joint. The clavicular long axis (Z-axis) is defined as the line between the AC and sternoclavicular joint centers. The Y-axis is defined as the axis perpendicular to the Z-axis and the AC joint line. The X-axis is defined as the axis perpendicular to the Y- and Z-axes.

(AC line: Acromioclavicular joint line)

Figure 3

Three dimensional deformities of the clavicle

Rotation angles are described in three dimensions.

Figure 4

Rotation angle deformity and length shortening percentage of the clavicle in the control and fracture groups (* $P < 0.05$, *** $P < 0.001$)

A: Downward angular deformity of the clavicle

B: Anterior angular deformity of the clavicle

C: Anterior axial rotation of the clavicle

D: Length shortening percentage of the clavicle

Figure 5

Relationships between rotation angles and clavicular length shortening

A: Relationship between clavicular shortening percentage and downward angular deformity

B: Relationship between clavicular shortening percentage and anterior angular deformity

C: Relationship between clavicular shortening percentage and anterior axial rotation

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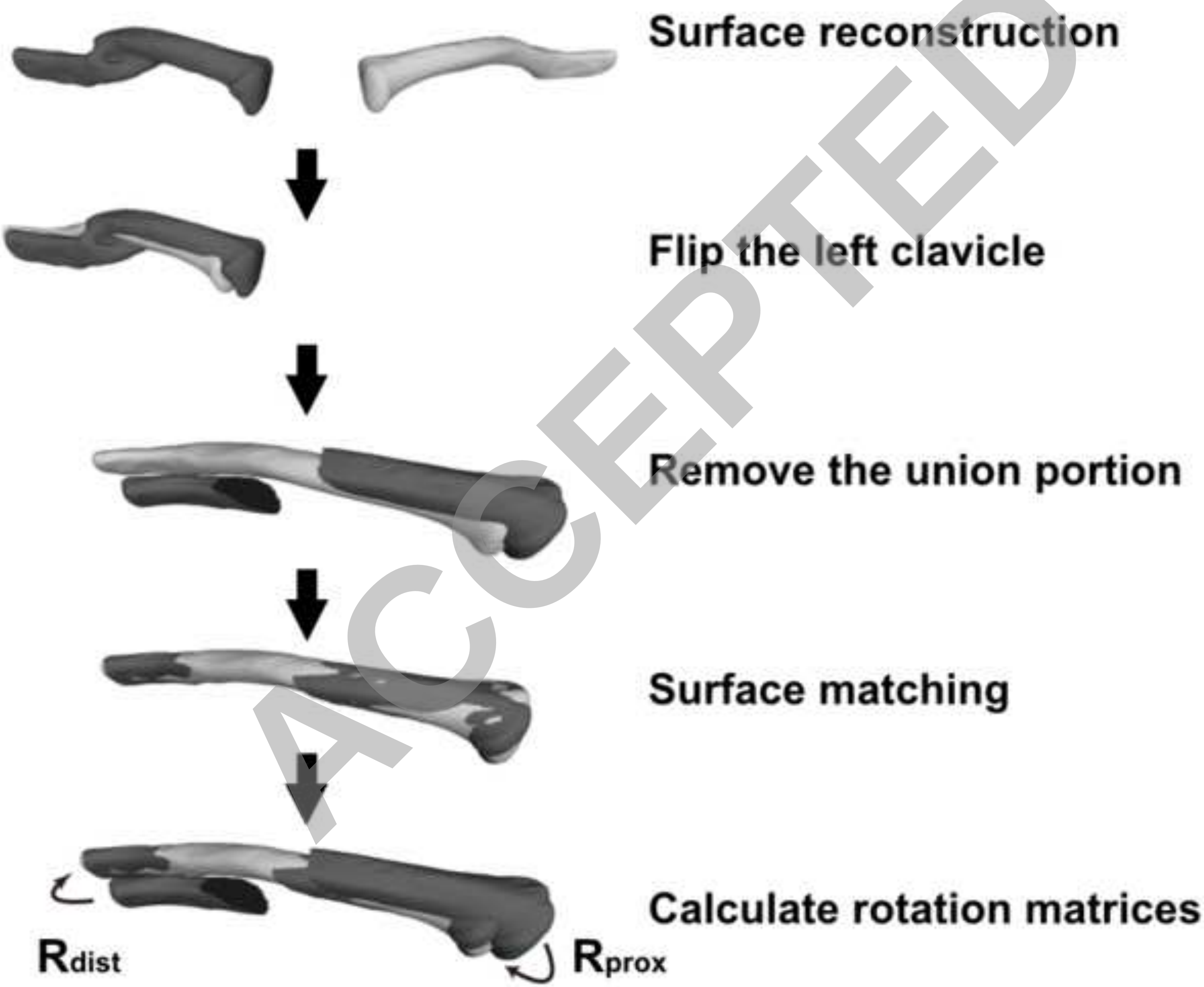
Figure 1



Surface reconstruction
Flip the left clavicle
Remove the union portion
Surface matching
Calculate rotation matrices
Rdist
Rprox

Figure 2

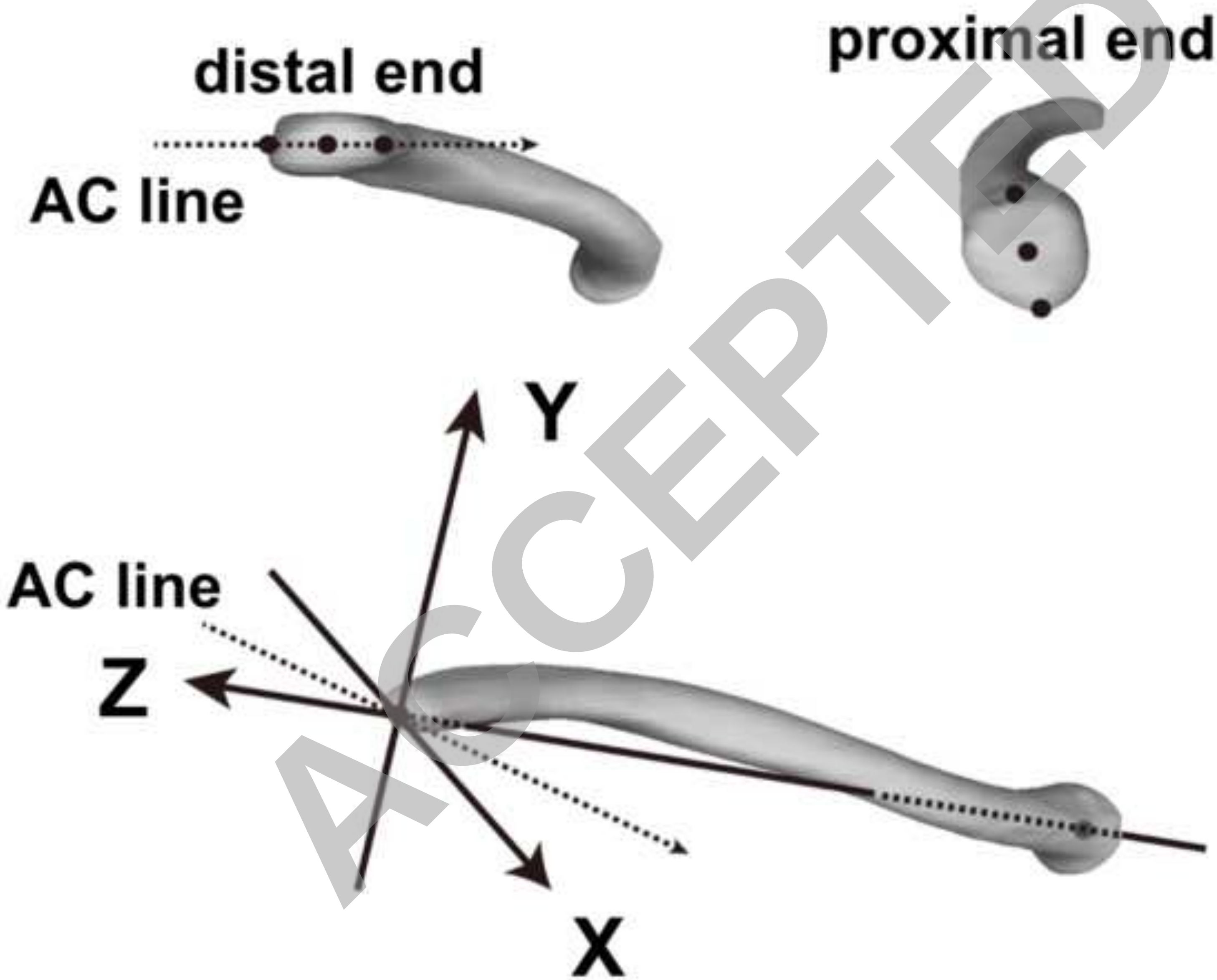


Figure 3

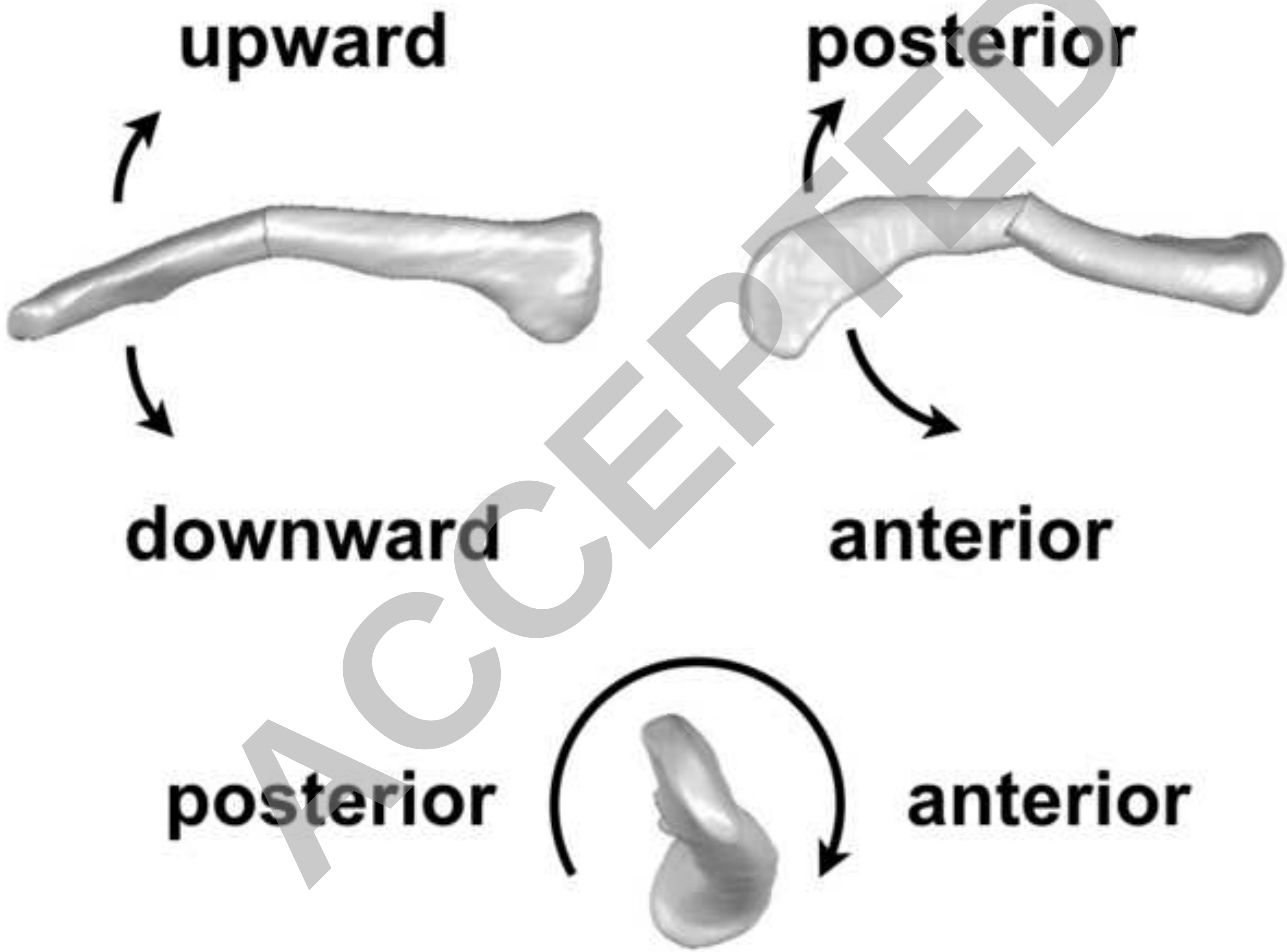
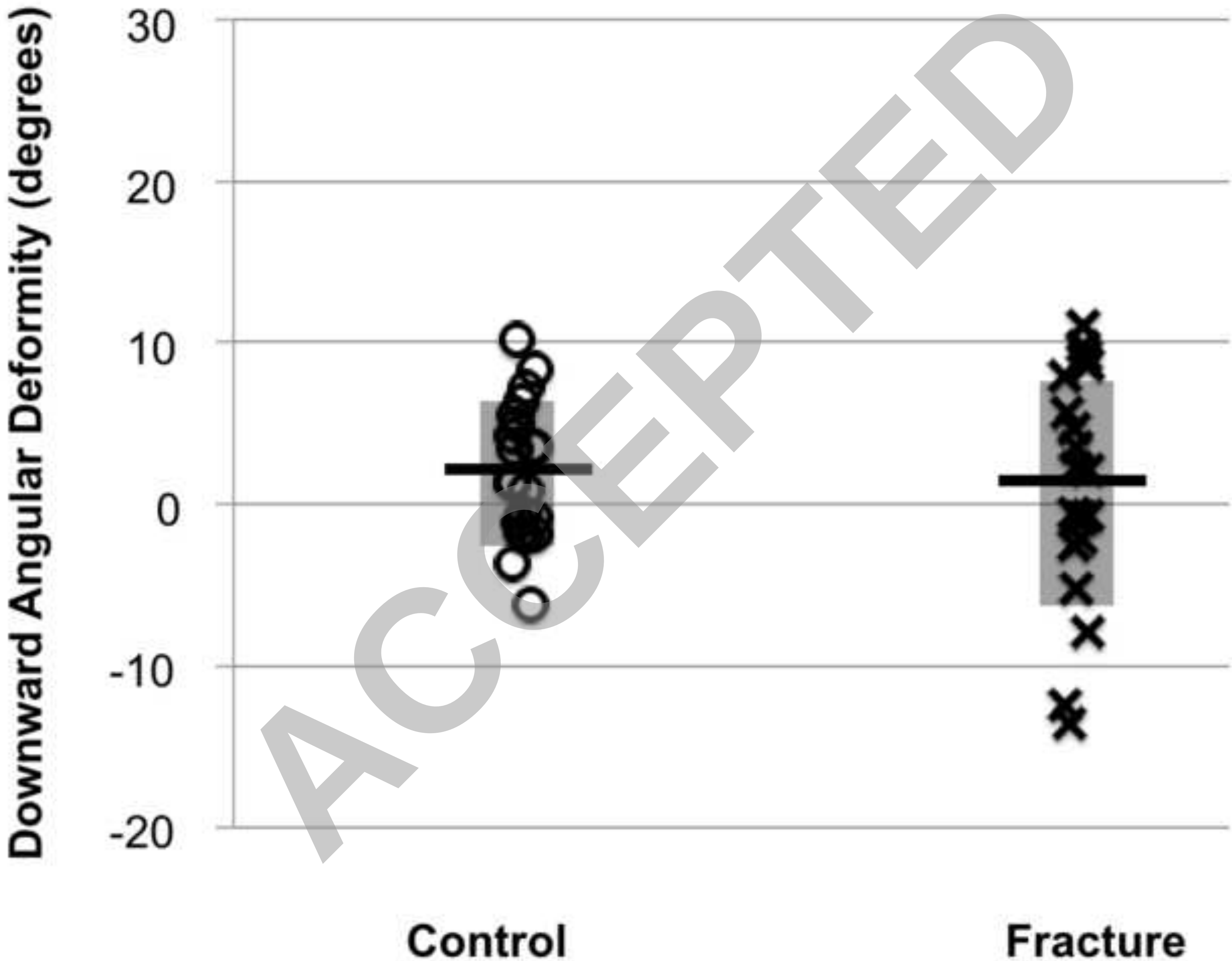


Figure 4A



Downward Angular Deformity (degrees)
30
20
10
0
-10
-20
Control
Fracture

Figure 4B

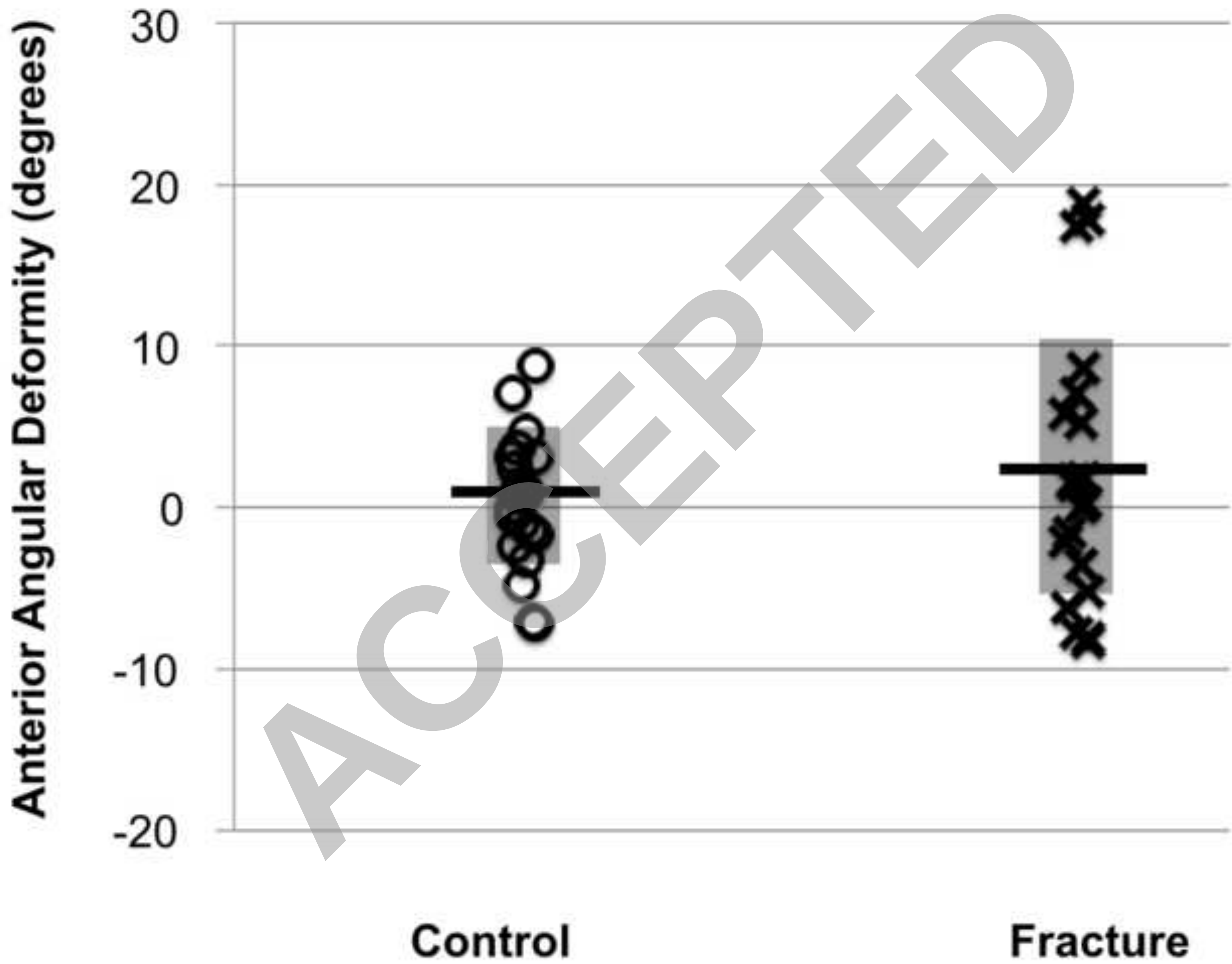
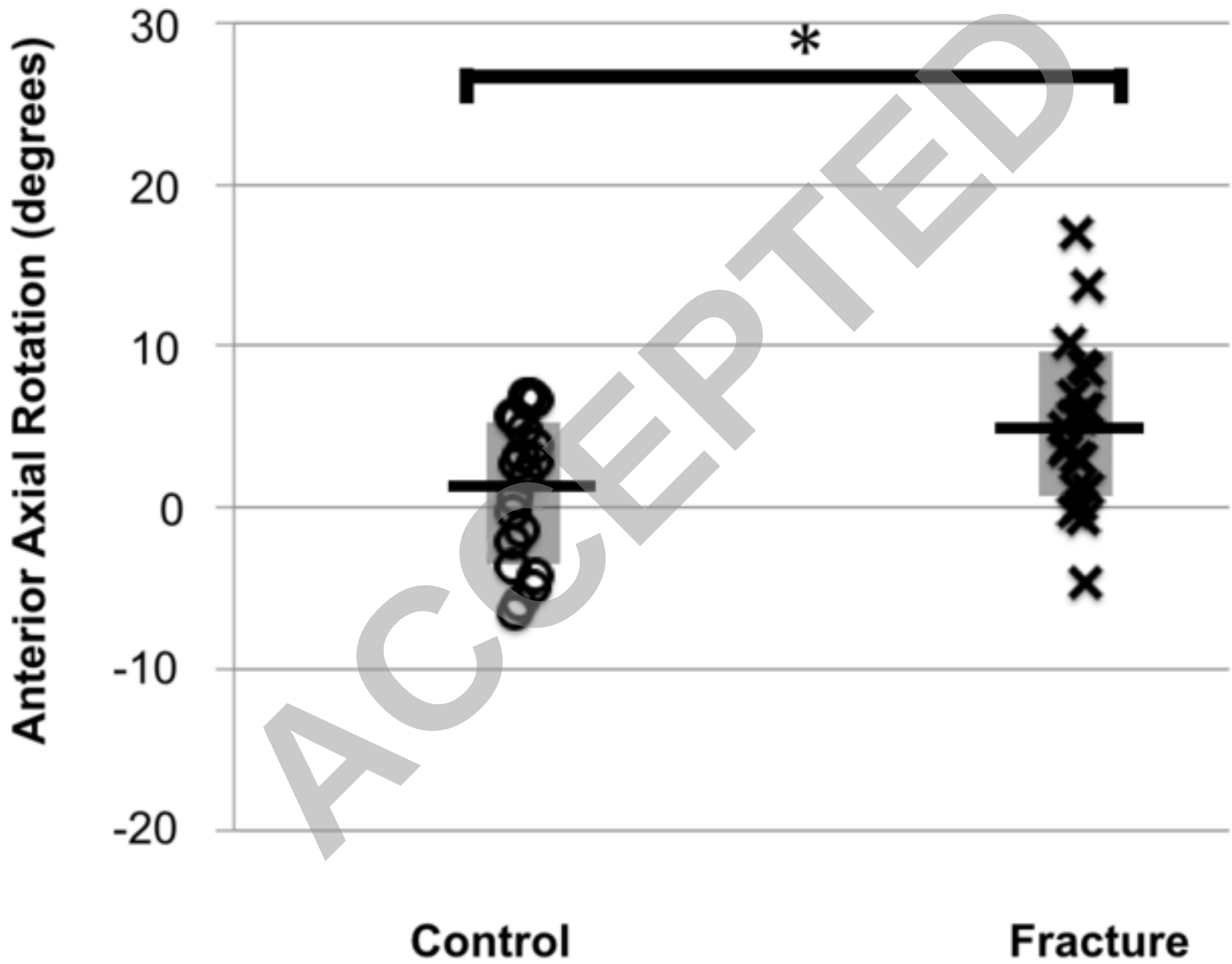
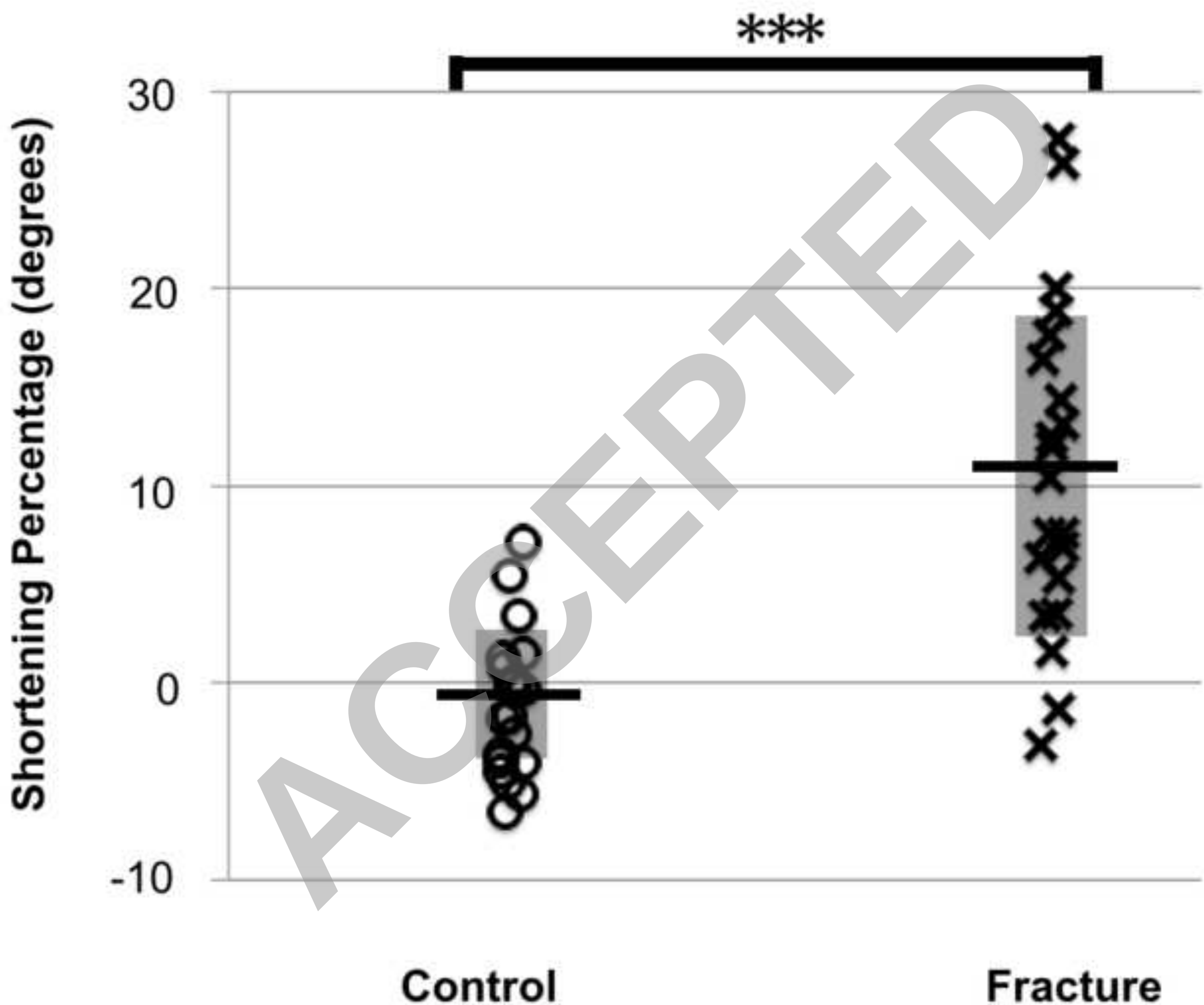

Anterior Angular Deformity (degrees)
30
20
10
0
-10
-20
Control
Fracture

Figure 4C



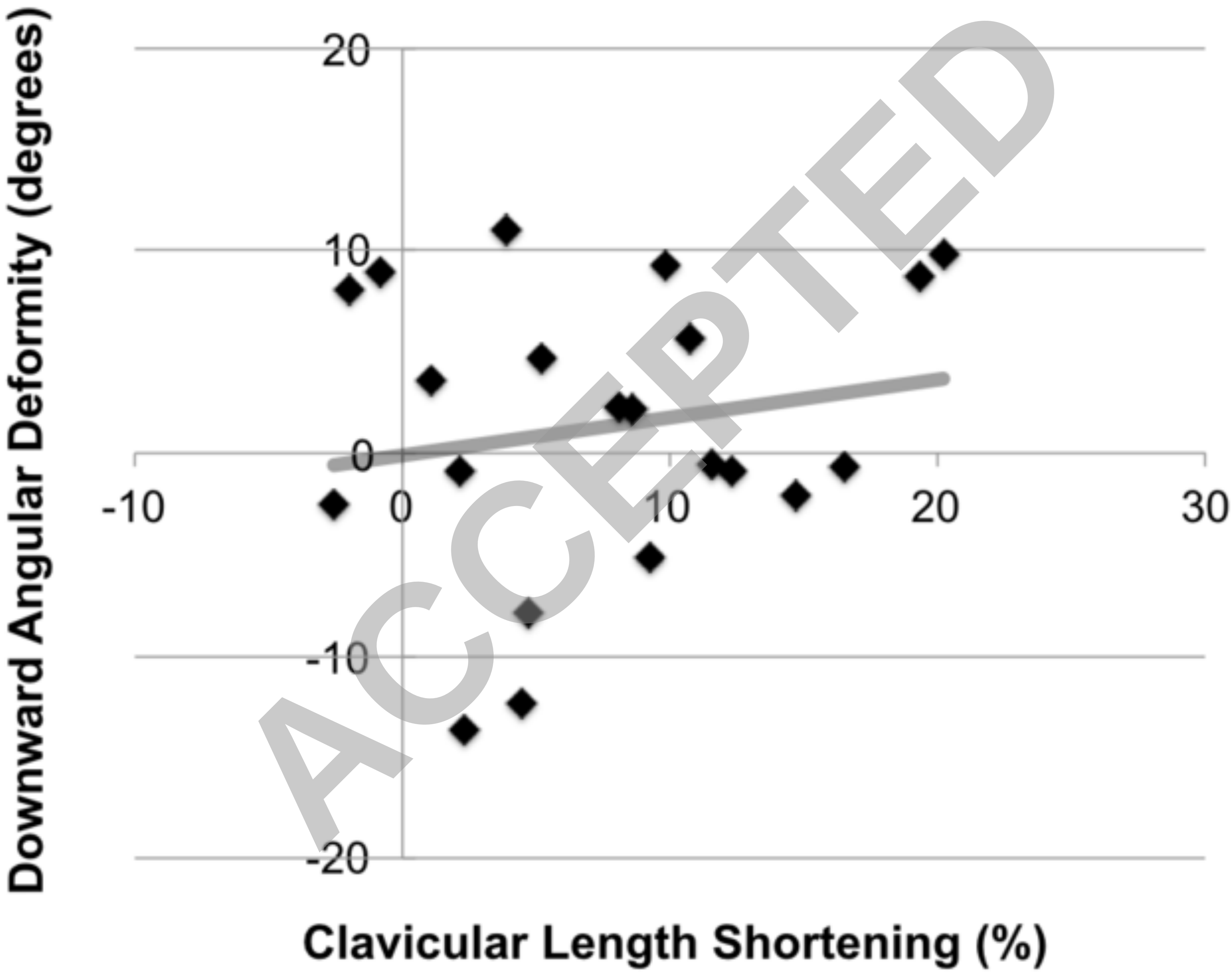
30
20
10
0
-10
-20
Anterior Axial Rotation (degrees)
*
Control
Fracture

Figure 4D



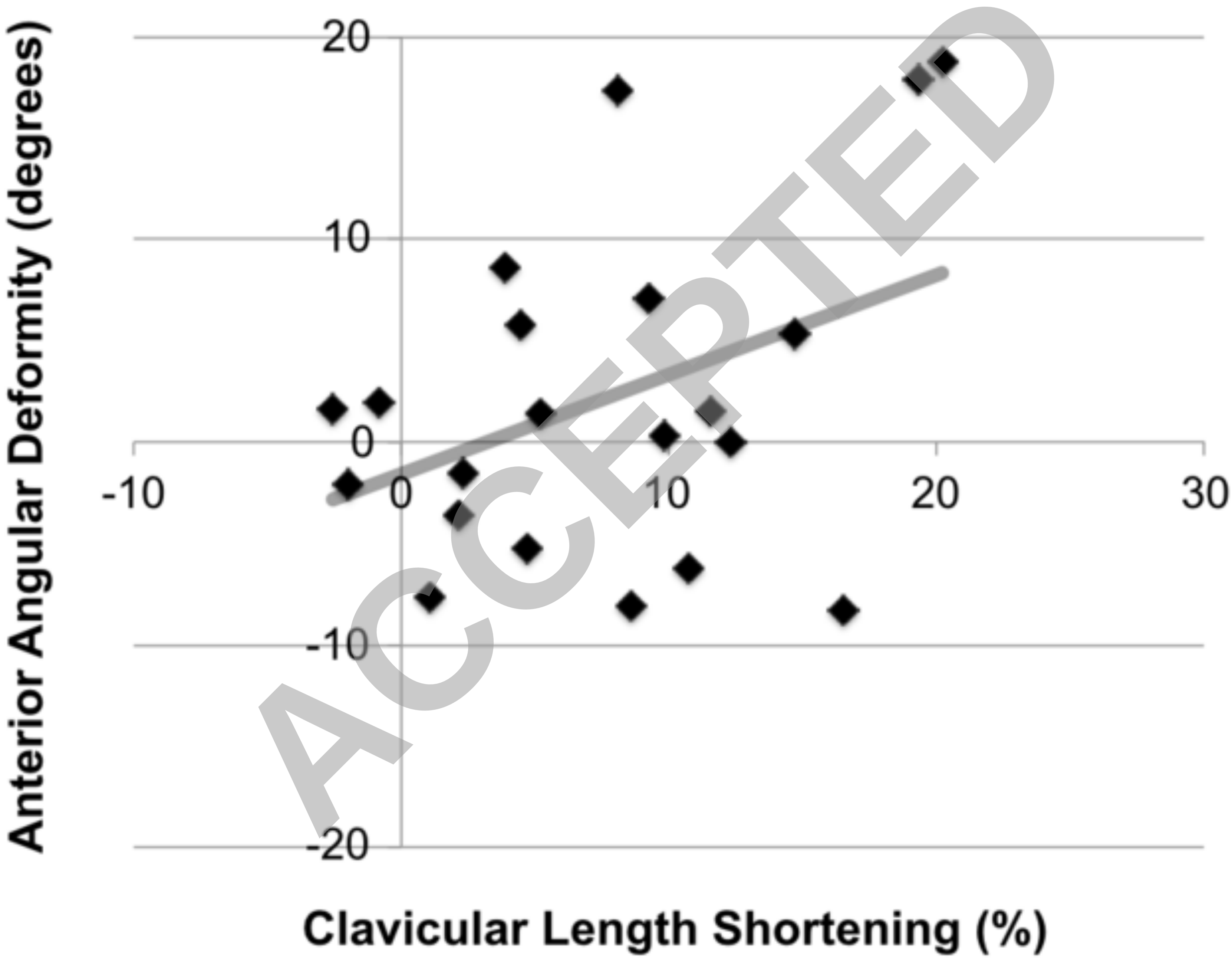
***
30
20
10
0
-10
Shortening Percentage (degrees)
Control
Fracture

Figure 5A



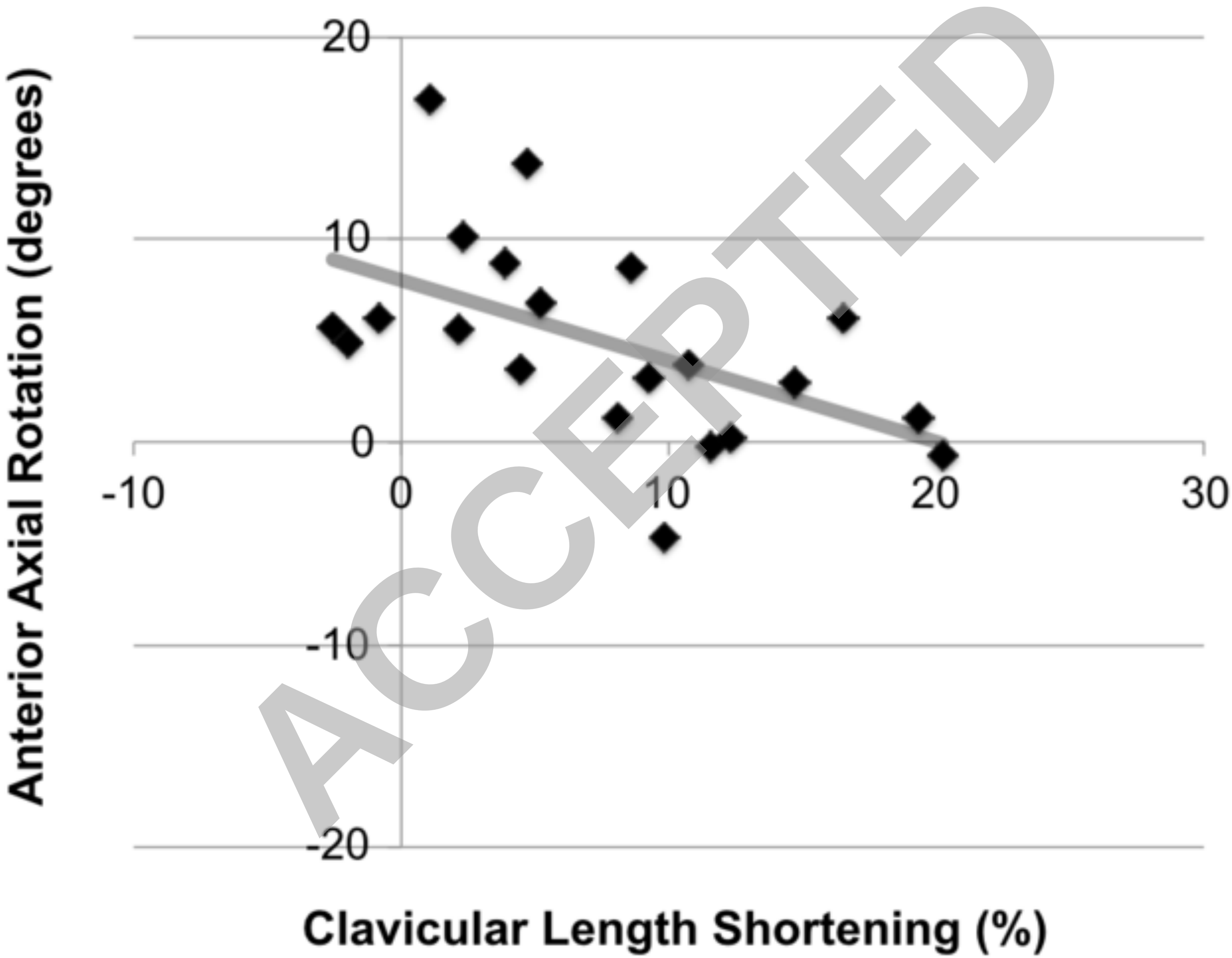
Downward Angular Deformity (degrees)
20
10
0
-10
-20
-10
0
10
20
30
Clavicular Length Shortening (%)
ACCEPTED

Figure 5B



ACCEPTED
20
10
0
-10
-20
-10
0
10
20
30
Anterior Angular Deformity (degrees)
Clavicular Length Shortening (%)

Figure 5C



20
10
0
-10
-20
-10
0
10
20
30
Anterior Axial Rotation (degrees)
Clavicular Length Shortening (%)
ACCEPTED