

**Anterior and Coracoid base tunnel location combined with single -or double clavicular tunnel techniques using double-button fixation for coracoclavicular ligament reconstruction both restore horizontal stability. A biomechanical cadaver study**

**Running Title: ACJ Horizontal Instability**

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**Highlights**

- Acromioclavicular joint reconstruction techniques don't address horizontal instability.
- Coracoid tunnel placement in double-button fixation may affect horizontal translation.
- At point zero, both single- and double-clavicle tunnels restores horizontal displacement.
- Anterior coracoid tunnel placement does not affect horizontal displacement.
- Single coracoid tunnel at the base and double clavicle provides the most stable reconstruction.

**Conflict of Interest Statement:**

The authors declare that they have no conflict of interest

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**MM:** Formal analysis; Funding acquisition; Investigation; Methodology; Project administration; Resources; Software; Supervision; Validation; Roles/Writing - original draft; and Writing - review & editing.

**NK:** Data curation; Investigation; Methodology; Project administration; Resources; Software; Roles/Writing - original draft; and Writing - review & editing.

**AO:** Data curation; Investigation; Methodology; Project administration; Resources; Software; Roles/Writing - original draft; and Writing - review & editing.

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### **Availability of data and materials**

Not applicable

### **Compliance with ethical standards**

The study was approved by the Research Ethics Committee

### **Conflict of interest**

The authors declare no conflict of interest with the presented body of research.

### **Ethical Approval**

The study was approved by the Research Ethics Committee

### **Informed Consent**

For this type of study informed consent is not required.

## **ABSTRACT**

**Background:** The placement of clavicle tunnels in coracoclavicular ligament reconstruction is well established, but the optimal position of the coracoid tunnel remains unclear. This study aimed to investigate how the coracoid tunnel's position affects horizontal stability during coracoclavicular ligament reconstruction using a double-button technique.

**Methods:** Fifteen fresh frozen shoulder cadaver specimens were tested under various conditions: intact coracoclavicular ligaments, disrupted ligaments, and reconstructions with a single coracoid and clavicle tunnel or double clavicle tunnels. The coracoid tunnel was positioned at the coracoid base 1/9, and 1/5 anterior to the base. Specimens underwent displacement-controlled loading, with 2D motion analysis conducted on captured digital images using TEMA motion analysis.

**Findings:** Mean displacement for intact coracoclavicular ligaments was  $1.61 \pm 0.92$  mm, and  $3.69 \pm 1.09$  mm for disrupted ligaments. For reconstructed conditions, displacements were as follows: Single-Tunnel Base ( $1.87 \pm 0.64$  mm), Single-Tunnel 1/9 ( $2.54 \pm 1.13$  mm), Single-Tunnel 1/5 ( $2.62 \pm 1.17$  mm), Double-Tunnel Base ( $1.25 \pm 0.73$  mm), Double-Tunnel 1/9 ( $2.03 \pm 1.22$  mm), and Double-Tunnel 1/5 ( $1.88 \pm 1.20$  mm). Differences among intact, reconstructed, and disrupted states were statistically significant ( $p=0.01-0.0001$ ), with all reconstruction techniques restoring horizontal displacement near the intact state.

**Interpretation:** At point zero both single coracoid tunnel and single- and double-clavicle tunnel restored horizontal displacement to its intact state. Coracoid tunnel placement anterior to the base of the coracoid did not influence horizontal displacement but single coracoid at the coracoid base and single clavicle tunnel resulted in the most anatomic reconstruction. Single coracoid tunnel at the base and double-clavicle resulted in the most stable reconstruction.

**Keywords:** Acromioclavicular joint; horizontal instability; AC joint dislocation; acromioclavicular ligament repair; acromioclavicular joint stabilization

## 1 Introduction

Mechanical trauma by either a direct blow to the shoulder girdle or falling onto an extended arm can result in disruption of the coracoclavicular (CC) ligaments (Martetschläger et al., 2019). In high-grade injuries, surgery is generally recommended (Berthold et al., 2022). Over 150 surgical techniques have been described (Dyrna et al., 2019). Currently, anatomic approaches have gained popularity and require the drilling of tunnels into the clavicle and coracoid (Berthold et al., 2022). The aim of reconstructing the coracoclavicular (CC) ligaments is to provide optimal postoperative acromioclavicular (AC) joint stability in both vertical and horizontal planes (Läderrmann et al., 2013; Saccomanno et al., 2014; Boffano et al., 2017).

Contemporary reconstructive techniques focus on restoring vertical AC-joint stability by reconstructing the CC ligaments (Thomas et al., 2011; Millet et al., 2015; Kibler et al., 2017). However, increased anterior-posterior translation of the lateral clavicle against the acromion commonly results in horizontal instability (Gonzalez-Lomas et al., 2010; Michlitsch et al., 2010; Beitzel et al., 2013; Saier et al., 2015) and persistent horizontal instability following CC ligaments reconstruction has been associated with poorer clinical results (Morikawa et al., 2019; Aliberti et al., 2020). Horizontal instability is often neglected or underdiagnosed (Aliberti et al., 2020).

Coracoid tunnel location is critical and even guided tunnel drilling may result in cortical breaches, coracoid process fractures and not reproduce the anatomy of the CC ligaments (Campbell et al., 2015; Koh et al., 2018; Coale et al., 2013). The placement of clavicle tunnels is well established; the trapezoid ligament originates at 17% and the conoid ligament at 31% of the total length of the clavicle (Rios et al., 2007). This corresponds with the lateral clavicle tunnel to be placed between 30-40 mm medial to the distal clavicle tip and a second tunnel 15-25 mm lateral to the first tunnel if the double-tunnel clavicle technique is intended (Buckley et al., 2021; Kennedy et al., 2019; Frank et al., 2017). However, the position of the coracoid tunnel is not well established and tunnel location may influence horizontal stability.

Therefore, the purpose of this biomechanical study was to investigate the effect of coracoid tunnel position on horizontal displacement during coracoclavicular (CC) ligament reconstruction using a double-button technique. It was hypothesised that the horizontal displacement would increase with a more anterior coracoid process tunnel position.

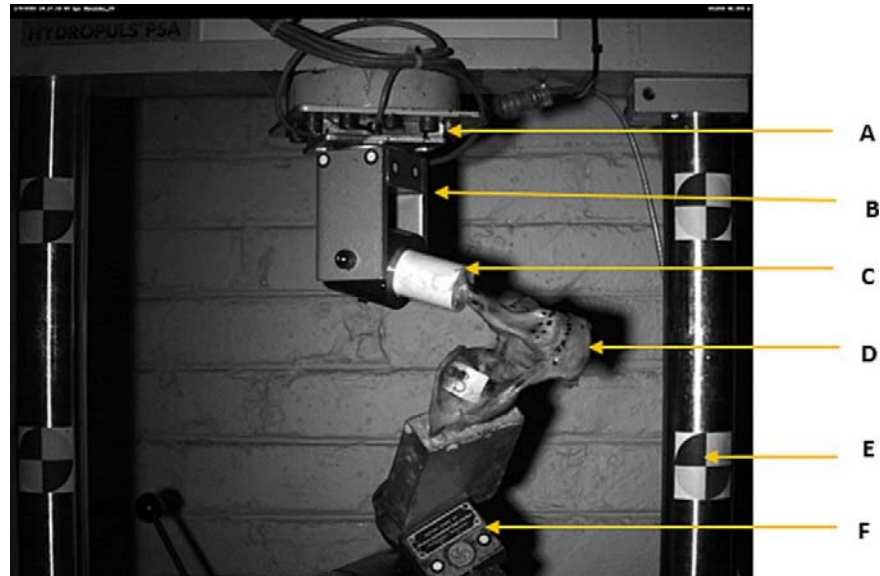
## 2 Methods

The shoulder specimens were procured from the National Tissue Bank under the auspices of the University of Pretoria, South Africa. Ethics approval was obtained prior to commencing the study from the University of Pretoria Research Ethics Committee (Reference No. 83/2019).

Specimens were included if they were from skeletally mature donors and did not show any macroscopic signs of damage. Specimens were also included if there were no obvious signs of previous surgery to the proximal humerus. Specimens were excluded if there was the presence of AC joint pathology and previous surgery to the acromion and clavicle. Specimens who had undergone shoulder replacement surgery were also excluded. Fifteen fresh cadaveric shoulder specimens (n=15), that met the inclusion and exclusion criteria, were finally included in the study. There were eight right and seven left shoulders. The sample comprised nine males and six females with an age range of 44-88 years. Before testing, all specimens were stored in a freezer (-5 degrees Celsius) and thawed at room temperature for at least 24 hours before testing.

## **2.1 Specimen Preparation**

To expose the CC ligaments, the humerus was disarticulated from the scapula by removing the deltoid attachment to the scapula and clavicle and further by removing the rotator cuff muscles, including the teres major from their attachments to the scapula. Once the soft tissues were removed, great care was taken to expose the CC ligaments, AC joint ligaments and capsule by removing any remaining soft tissues (trapezius fibres, deltoid fibres), ensuring that the CC ligaments and AC joint capsule remained intact. The length of the clavicle, coracoid process, and CC ligaments were measured with a calibrated digital calliper accurate to 0.01mm. A custom-made mounting jig was used to fix the specimens onto the testing apparatus. The lower 50% of the body of the scapula was potted with gypsum into an open rectangular metal box. This fixation technique allowed the spine of the scapula, glenoid, and coracoid process to project freely. A 40mm Polyvinyl chloride pipe (PVC) was filled with gypsum to secure the medial one-third of the clavicle. The long axis of the clavicle was centred within the PVC pipe, and the gypsum was allowed to harden over 24 hours before testing. Once the shoulder specimen had been assembled on the testing machine, all the testing was performed without altering the initial assembled position (Figure 1). To prevent desiccation during testing, each specimen was kept moist by regularly spraying with a normal saline solution.

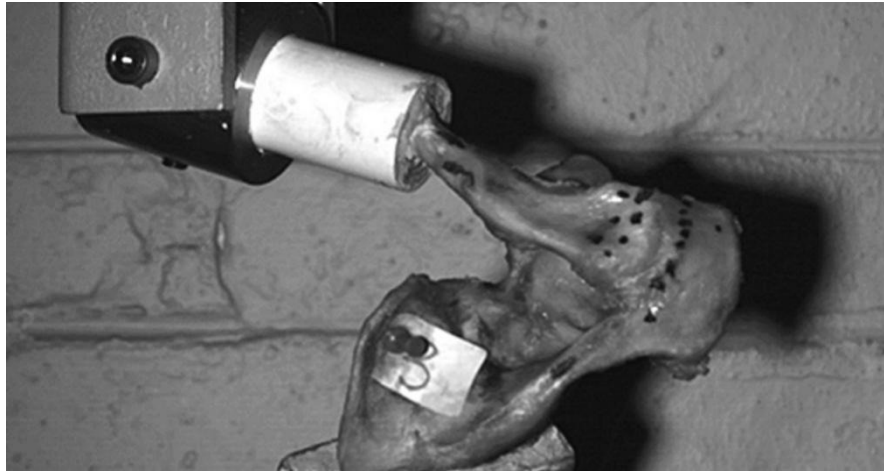


**Figure 1:** Right shoulder mounted on the Hydropuls testing machine. Load cells (A), custom-made jig (B), gypsum-filled polyvinyl chloride pipe with the clavicle (C), gypsum-filled rectangle metal box with the scapula (D), motion tracking reference marker (E), bottom clamp (F).

## 2.2 Biomechanical testing

Biomechanical testing was performed using a 100kN Hydropuls Universal Testing Machine (UTM). Custom-made clamps were used to rigidly mount the potted specimens onto the UTM. The clamps allowed five degrees of freedom ensuring that the AC joint was correctly aligned in the vertical and horizontal planes. Following load cell calibration, the specimens were loaded on the Hydropuls machine (Figure 1). All the specimens were subjected to displacement-controlled loading at a constant rate of 25mm/min for 15 seconds with a maximum allowed displacement to 6.25mm. An alcohol-based ink with a rubber dropper was used to create random speckle patterns on either side of the AC joint surface (Figure 2). This technique was previously described by Crammond et al. (Crammond et al., 2013) and validation studies demonstrated high accuracy (Crammond et al., 2013; Titkov and Panin, 2019). for displacement and stress/strain assessment of materials when using digital image correlation. An IDT NX8-S2 camera was used to capture video of the lateral third clavicle and acromion centred over the AC joint during testing. 2D motion analysis was performed on the captured images using TEMA motion analysis software. Prior to analysis, camera intrinsic and extrinsic parameters were obtained via camera calibration. This ensured that the internal camera geometric and optical characteristics (including lens distortion characteristics) as well as camera orientation was accurately captured in order to produce high-accuracy results (Heikkilä & Silvén, 1997; Sutton et al., 2009). To facilitate this, pictures were captured with the camera of a suitable calibration board on a daily basis. Four static quadrant markers with known interpoint distances were placed on the UTM frame such as to define the reference motion plane for analysis, and also for extrinsic calibration of the camera (i.e., spatial resolution and orientation) during analysis. This approach allowed the horizontal

displacement of the distal clavicle to be measured accurately using multiple points on both sides of the AC joint without altering the mechanical properties of the specimens.



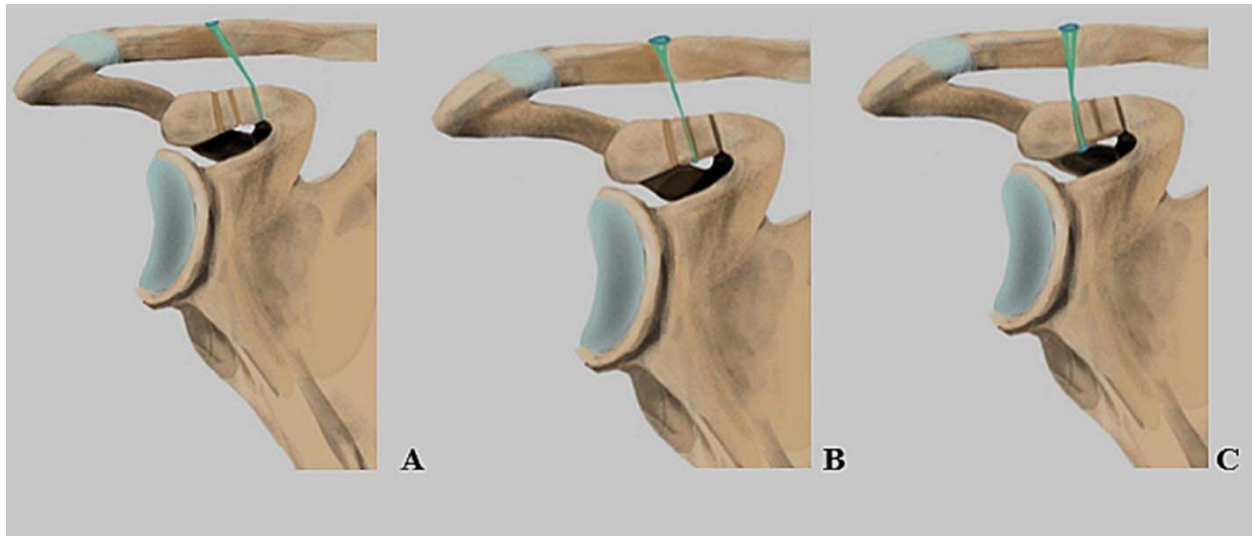
**Figure 2:** The right acromioclavicular joint specimen demonstrates tracking markers on the lateral clavicle and the medial part of the acromion. The tracking markers were created with an alcohol-based ink rubber stopper.

## 2.3 Surgical technique

Before surgical reconstruction was performed, horizontal displacement of the intact and transected CC ligament was tested.

### 2.3.1 Single Transclavicular-Transcoracoid Technique (ST)

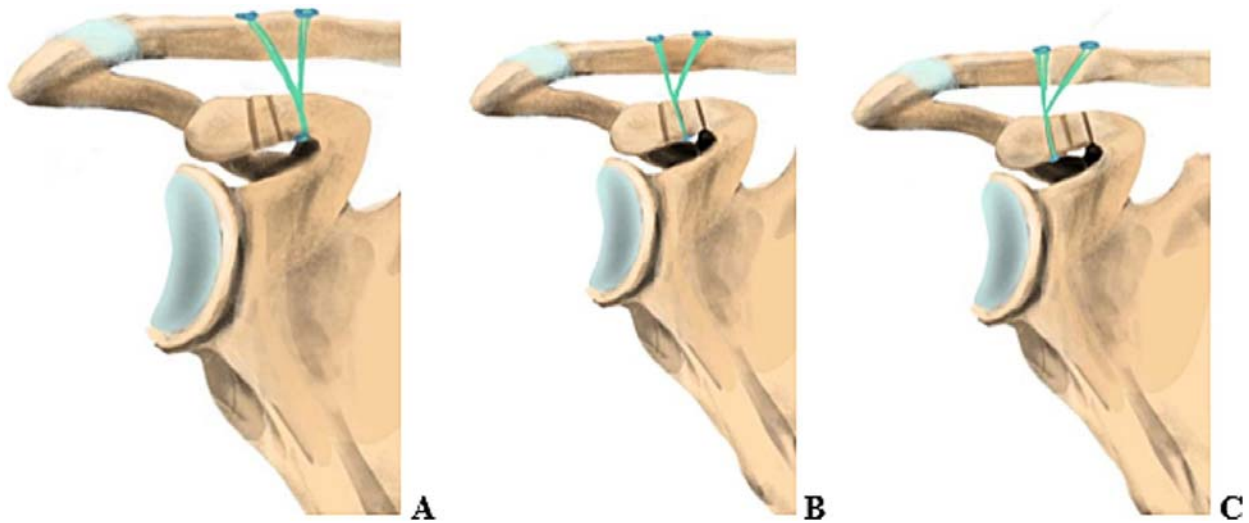
A single transclavicular tunnel centrally placed at 20 mm medial to the AC joint. A 2 mm K-wire was placed perpendicular to the superior surface of the clavicle, and a 4-mm cannulated drill bit was used to complete the tunnel. The length of the coracoid was measured from the base to the tip at the inferior surface using a digital calliper. The initial tunnel was placed at the base (STO) using the same technique as for clavicle tunnel drilling. The second coracoid tunnel was placed at 1/9 (STO1/9) from its base and the third tunnel was placed at 1/5 (ST1/5) from the coracoid base. A cortical fixation button device (TightRope, Arthrex, Naples, FL, USA) was used for reconstruction, and the manufacturer's recommendations were followed. The two traction sutures from the oblong button were shuttled with a Nitinol Suture Lasso, and the button was flipped, making sure that the button was placed 90 degrees to the long axis of the coracoid. Pulling on the tightrope sutures, the round button was advanced to the superior surface of the clavicle, manually tightened and secured with four half-stitches (Figure 3).



**Figure 3:** Illustration of a cortical fixation button device containing four strands of No. 5 suture were inserted on the clavicle superior surface. Single transclavicular hole was placed 2 cm medial to the acromioclavicular joint centrally on the clavicle. The coracoid process tunnel position at the base (A), 1/9 (B) and 1/5(C) from the base with the suspension device secured in place.

### ***2.3.2 Double Transclavicular-Transcoracoid Technique (DT)***

The second transclavicular tunnel was placed 40 mm medial to the AC joint. A 2 mm K-wire was placed perpendicular to the superior surface of the clavicle, and a 4-mm cannulated drill bit was used to complete the tunnel. The coracoid tunnels were created using the same technique as described above for the ST technique. The lateral button was shuttled first followed by the medial button. This was done to ensure that the ST technique was supplemented with the lateral button. The medial button was flipped and placed 90 degrees to the long axis of the coracoid, tightened by hand advancing the clavicle round button onto the superior surface of the clavicle. Once secured, the lateral button was flipped and placed 90 degrees to the direction of the medial coracoid button, effectively placing the medial button in line with the longitudinal axis of the coracoid. The reconstruction was completed by pulling on the tightrope sutures and manually tightening of the round button. The knots were secured with four half-stitches (Figure 4). To reduce confounders, all reconstructions were performed by a single fellowship-trained orthopaedic surgeon.



**Figure 4:** Illustration of two cortical fixation button devices containing four strands of No. 5 suture were inserted on the clavicle superior surface. Double transclavicular holes were placed at 2cm and 4cm medial to the AC joint centrally on the clavicle. The coracoid process tunnel position at the base 0 (A), 1/9 (B) and 1/5(C) from the base with the two suspension devices secured in place.

## 2.4 Biomechanical Testing Protocol

Each specimen was subjected to a total of eight tests.

**Test-1:** Horizontal displacement testing with intact AC and CC ligaments. Each specimen was mounted on the Hydropuls testing machine using the jig and clamps, ensuring the same horizontal and vertical position. The position of the AC joint was recorded using the digital data and speckle patterns (DIC) prior to testing. This served as the baseline position for the subsequent tests.

**Test-2:** Horizontal displacement testing with disrupted CC ligaments. Using the data from DIC, the UTS placed the joint at the baseline position. The specimens were not removed from the testing machine for CC ligament dissection. A surgical blade was used to completely transect/disrupt at the mid-substance of the conoid and trapezoid ligaments.

**Test-3:** Horizontal displacement testing following reconstruction with single transclavicular and transcoracoid tunnel reconstruction at the coracoid base (ST-0). Using the data from DIC, the UTS placed the joint at the baseline position. Surgical reconstruction was then performed on the mounted specimen as described above. This approach was also used for the following test conditions.

**Test-4:** Horizontal displacement testing following reconstruction with single transclavicular and transcoracoid tunnel reconstruction at 1/9 from the coracoid base (ST-9).

**Test-5:** Horizontal displacement testing following reconstruction with single transclavicular and transcoracoid tunnel reconstruction at 1/5 from the coracoid base (ST-5).

**Test-6:** Horizontal displacement testing following reconstruction with double transclavicular and single transcoracoid tunnel reconstruction at the coracoid base (DT-0).

**Test 7:** Horizontal displacement testing following reconstruction with double transclavicular and single transcoracoid tunnel reconstruction at 1/9 from the coracoid base (DT-9).

**Test 8:** Horizontal displacement testing following reconstruction with double transclavicular and single transcoracoid tunnel reconstruction at 1/5 from the coracoid base (DT-5).

## 2.5 Statistical Analysis

Descriptive statistics were used to describe and summarize the collected data. Normal data distribution was analysed using the Shapiro-Wilks test. If the data were normally distributed, means and standard deviations were calculated. If the data was not normally distributed, the median as a measure of central tendency and the range as a measure of variability was calculated. To check for outliers the Grubbs test was used. One-way ANOVA was used for multiple group comparisons. In the event of a significant main effect or interaction, post hoc comparisons (Tukey's HSD) were conducted using the least significant differences. A level of significance of  $p < 0.05$  was selected for all analyses. All analyses were conducted using STATA SE (Version 12.0; StataCorp, College Station, Texas, USA) for Windows.

## 3 RESULTS

### 3.1 Horizontal displacement

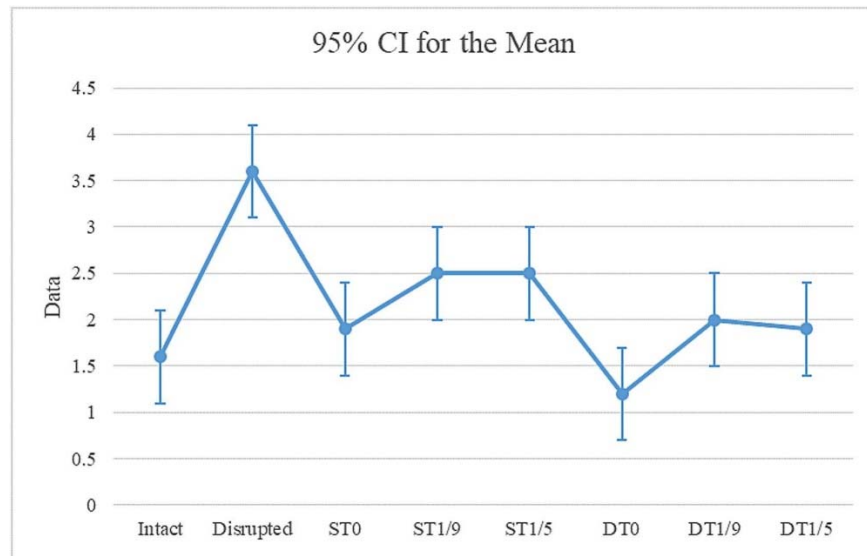
Table 1 and Figure 5 present the results of horizontal displacement for each testing condition. The mean baseline horizontal displacement for intact CC ligaments performed was 1.6 mm ( $\pm 0.91$ ). Following the mid-substance transection of the CC ligaments, the mean horizontal displacement was 3.69 mm ( $\pm 1.09$ ). Reconstructing the AC joint with a single tunnel (ST) technique at the coracoid base (ST-0), 1/9 (ST-9) and 1/5 (ST-5) from the base resulted in a mean AC joint horizontal displacement of 1.87 mm ( $\pm 0.64$ ), 2.54 mm ( $\pm 1.13$ ) and 2.62 mm ( $\pm 1.17$ ), respectively. Reconstruction techniques which utilized a coracoid base tunnel (ST0 and DT0) and DT1/9 and DT 1/5 restored horizontal stability closest to its native state.

**Table 1: Results of horizontal displacement**

	TEST 1 Intact	TEST 2 Disrupted	TEST 3 ST- 0	TEST 4 ST-9	TEST 5 ST-5	TEST 6 DT-0	TEST 7 DT-9	TEST 8 DT-5
<b>MEAN</b>	<b>1.61</b>	<b>3.69</b>	<b>1.87</b>	<b>2.54</b>	<b>2.62</b>	<b>1.25</b>	<b>2.03</b>	<b>1.88</b>
<b>SD</b>	<b>0.92</b>	<b>1.09</b>	<b>0.64</b>	<b>1.13</b>	<b>1.17</b>	<b>0.73</b>	<b>1.22</b>	<b>1.2</b>
<b>Minimum</b>	<b>0.1</b>	<b>1.4</b>	<b>0.6</b>	<b>0.8</b>	<b>0.8</b>	<b>0.2</b>	<b>0.4</b>	<b>0.1</b>
<b>Maximum</b>	<b>3.0</b>	<b>5.8</b>	<b>3.3</b>	<b>4.8</b>	<b>4.5</b>	<b>2.3</b>	<b>4.9</b>	<b>4.6</b>
<b>RANGE</b>	<b>2.9</b>	<b>4.4</b>	<b>2.6</b>	<b>4.0</b>	<b>3.6</b>	<b>2.1</b>	<b>4.5</b>	<b>4.5</b>
<b>95% CI</b>	<b>1.1 – 2.1</b>	<b>3.0 – 4.3</b>	<b>1.4 – 2.3</b>	<b>1.9 – 3.2</b>	<b>1.9 – 3.1</b>	<b>0.8 – 1.6</b>	<b>1.4 – 2.7</b>	<b>1.2 – 2.5</b>

Measurements in millimetres

ST, single transclavicular tunnel; DT, double transclavicular tunnel; 0-tunnel at the coracoid base, 1/5-tunnel at one fifth from the coracoid base, 1/9-tunnel at one ninth from the coracoid base.



**Figure 5:** Interval plot of Tests graph showing the means and 95% confidence intervals for the intact, disrupted and reconstructed groups. This graph visually shows that all reconstructions ultimately restored horizontal instability of the acromioclavicular joint to its native state. ST, single transclavicular tunnel; DT, double transclavicular tunnel; 0-tunnel at the coracoid base, 1/5-tunnel at one fifth from the coracoid base, 1/9-tunnel at one ninth from the coracoid base. Data of displacement is shown in millimeters.

One-way ANOVA revealed that there were statistically significant between group difference in mean horizontal displacement ( $F=7.81$ ,  $p=0.0001$ ). Post hoc comparisons with Tukey's-test revealed that these differences were only statistically significant between the intact and disrupted

condition ( $p=0.0001$ ) and all reconstructed techniques and the disrupted condition ( $p=0.0001-0.023$ ). The Grubbs test did not demonstrate any outliers for all test conditions ( $p=1.0$ )

## 4 DISCUSSION

While the restoration of vertical stability following surgical fixation of acromioclavicular joint dislocation is well established using double-button fixation, horizontal instability remains a significant concern. The positioning of the coracoid tunnel may influence increased movements in the horizontal plane, which could be mitigated through appropriate coracoid tunnel placement. The aim of this biomechanical study was therefore to examine the impact of coracoid tunnel position on horizontal displacement during coracoclavicular (CC) ligament reconstruction using the double-button technique. The results of this biomechanical study demonstrated that both single-button and double-button surgical reconstruction using one single coracoid tunnel and either a single- or double-clavicle tunnel reliably restored horizontal stability. The restoration was also not affected by surgical technique (single- or double-button) or coracoid tunnel position. However, reconstruction techniques which utilized a coracoid base tunnel restored horizontal stability closest to its native state.

Increased anterior-posterior translation of the lateral clavicle against the acromion commonly results in horizontal instability (Gonzalez-Lomas et al., 2010; Michlitsch et al., 2010; Saier et al., 2015). Unfortunately, most of the described surgical techniques used for acromioclavicular (AC) joint reconstruction mainly focus on vertical stability (Aliberti et al., 2020). In fact, a recent systematic review suggested that horizontal instability injuries are often neglected or poorly understood which could result in failure after surgical stabilization stability (Aliberti et al., 2020). Ultimately horizontal instability needs to be addressed to achieve AC joint integrity and satisfactory clinical outcomes.

The treatment of horizontal instability has been addressed by various authors. Deshmukh et al. compared the Weaver-Dunn technique to suture cerclage and four different suture anchor techniques and reported that none of the techniques was able to restore acromioclavicular stability to normal (Deshmukh et al., 2004). Hislop et al. investigated the biomechanical strength of single clavicular tunnel and double-clavicular tunnel with and without suture augmentation across the AC joint with suture augmentation (Hislop et al., 2018). The authors reported that none of the three techniques could restore horizontal stability. Banffy et al. compared anatomic double- and single tunnel with semitendinosus graft, suture tape augmentation and PEEK tenodesis screws for fixation (Banffy et al., 2018). In their study, single tunnel CC ligament reconstruction demonstrated biomechanical properties equivalent to the double tunnel CC ligament reconstruction and both techniques restored horizontal stability to its intact state (Banffy et al., 2018). Beitzel et al. compared AC joint reconstruction with semitendinosus graft using various tunnel, over the top and under the coracoid techniques (Beitzel et al., 2014). The authors demonstrated that wrapping and direct suturing of the graft around the AC joint was the only technique that could restore horizontal stability (Beitzel et al., 2014). Park et al. suggested that triple-bundle reconstruction with an additional posterolateral bundle resulted in better

antero-posterior stability (Park et al., 2018). However, Park et al. utilized an additional implant across the AC joint during double-bundle reconstruction and this has most likely increased the stability of the reconstruction (Park et al., 2018).

It appears that reconstruction or reinforcement of the AC joint capsule significantly contributes to horizontal stability. Dyrna et al. investigated the effect of AC joint capsule repair with five different techniques and could clearly demonstrate that the combined reconstruction of both the AC capsule and CC ligaments achieved the highest percentage of regained resistance torque but remained significantly weaker than the native specimen (Dyrna et al., 2018). In a recent current concept article, the authors proposed that acute AC joint dislocations should be treated with arthroscopic assisted reconstruction of both AC joint and CC ligaments and in chronic cases, the stabilization should be augmented with a biological graft (Berthold et al., 2022). Similarly, Aliberti et al. performed a systematic review and included 23 studies (Aliberti et al., 2020). Aliberti et al. concluded that surgical procedures which included reconstruction of the horizontal component showed improved patients outcomes (Aliberti et al., 2020).

In contrast to the above studies, the results of this study do not seem to confirm that additional augmentation of the AC joint capsule is required to restore horizontal instability. However, the findings suggest that the coracoid tunnel should be close or at the base of the coracoid. When placing the tunnel at 1/9 or 1/5 anterior to the coracoid base, horizontal displacement increased by 36% compared to the native state. In contrast, reconstruction with clavicular double-tunnel and coracoid tunnel placement at the base resulted in a 25% decrease in horizontal displacement. Theoretically, this could cause an element of over-constraint. These differences were not statistically significant, and the 95% confidence intervals overlapped, suggesting that both increased and decreased horizontal displacement is possibly not clinically relevant. Jordan et al. performed a systematic review and reported that augmentation of the AC joint provides improved horizontal stability but does not show any clinical advantage (Jordan et al., 2019). The authors concluded that their findings do not support AC joint capsule augmentation in routine practice (Jordan et al., 2019). Unfortunately, between-study comparison is difficult as several testing protocols and reconstruction techniques limit the ability to compare similar techniques (Verstraete et al., 2023).

As discussed earlier, tunnel location influences horizontal stability. A non-significant increase in horizontal displacement was observed if the coracoid tunnel was placed more anterior. Campbell et al. investigated the effect of tunnel size and location on ultimate failure and demonstrated that load to failure was higher for a more central tunnel (Campbell et al., 2015). In addition, the placement of the tunnel closer to the coracoid base resulted in a substantial reduction in horizontal displacement (Campbell et al., 2015). Gao et al. combined a cadaver study with a finite element model and showed that coracoid tunnel placement 5 mm anterior to the coracoid base demonstrated the highest rotational stability with the lowest maximal displacement and lowest Mises stresses (Gao et al., 2023). However, anatomic central coracoid tunnel placement is possibly associated with complications. Koh et al. demonstrated a higher risk of coracoid fracture (Koh et al., 2018). However, Koh's et al. (Koh et al., 2018) findings are in contrast to an

earlier study. Ferreira et al. demonstrated that a centre-centre or medial-centre tunnel location lessens the risk of coracoid fracture (Ferreira et al., 2012).

#### **4.1 Limitations**

This study has the inherent weaknesses of any cadaveric study, which include a small sample size and the age of the cadavers. This study only investigated displacement at point zero and CC-ligament and AC joint capsule healing may contribute to further stability in clinical cases. The role of the surrounding soft-tissue envelope was not considered or simulated. It is possible that the delto-trapezial fascia and other secondary stabilisers could result in increased or decreased horizontal stability. Bone density measures were not performed. However, it is unlikely that differences between specimens in bone density would have influenced the results. Theoretically, tunnel breaks, suture pull-outs or button displacement could have been caused by low bone density, and these were not observed. For biomechanical testing a time-displacement mode limited to 15 seconds was used. It is possible that the displacement after 15 seconds could have followed an exponential pattern substantially influencing results. Load to failure was not performed.

#### **5 Conclusion**

At point zero both single coracoid tunnel and single- and double-clavicle tunnel restored horizontal displacement to its intact state. Coracoid tunnel placement anterior to the base of the coracoid did not influence horizontal displacement but single coracoid at the coracoid base and single clavicle tunnel resulted in the most anatomic reconstruction. Single coracoid tunnel at the base and double clavicle resulted in the most stable reconstruction.

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