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SURGICAL TREATMENT OF SHOULDER INJURIES BY THE WEAVER DUNN TECHNIQUE

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Abstract. The upper limbs are constituted by the shoulder, arm, forearm and hand. The shoulder consists of the sternoclavicular, acromioclavicular and shoulder joints. The acromioclavicular joint is stabilized by ligaments and deltoid and trapezius muscles. The ligaments which constitute this joint are the acromioclavicular, coracoacromial and coracoclavicular, that is divided into trapezoid and conoid. The joint can be injured due to the direct fall on shoulder or on extended upper limb and are common in sports with hard contact. The acromioclavicular dislocation is classified into different types and there are specific treatments for each one. The Weaver Dunn technique is one of the most common and consists in removing the intact coracoacromial ligament of the acromion, followed by its direct attachment to the structure of the clavicle. In this study, the Weaver Dunn technique was evaluated and the analysis of the influence of coracoacromial ligament transfer was performed using three-dimensional models by the finite element method. In intact acromioclavicular joint, considering the proposed conditions, the trapezoid ligament showed higher stress values. The distance between the clavicle and the coracoid process showed similar behavior among the technique evaluated and the intact joint. Thus, considering the simplifications and the conditions proposed for the models, it was concluded that the transfer of the coracoacromial ligament is an efficient technique to stabilize the acromioclavicular dislocation.

1 INTRODUCTION

The upper limbs are characterized by their mobility and ability in grasping and manipulating, being composed by the shoulder, arm, forearm and hand. The shoulder connects the upper limb to the upper body and consists of the sternoclavicular, acromioclavicular and shoulder joints that exhibit simultaneous movements. The occurrence of functional failures in any of the parts affect the movement of the entire structure [1].

The acromioclavicular joint has four degrees of freedom that allow movement in the anterior/posterior planes and lower/upper planes, being stabilized by static and dynamic elements. The deltoid and trapezius muscles act as dynamic stabilizers and the ligaments function as static stabilizers. The ligaments which constitute this joint are the acromioclavicular, coracoacromial and coracoclavicular, that is divided in trapezoid and conoid[2]. Although the joint has high strength coracoclavicular ligaments, it can be injured easily, due to the direct fall on the shoulder with the arm in the adducted position or due to fall on the outstretched upper limb.

The main treatments for acromioclavicular dislocation are based on the acromioclavicular ligament repair using pins, screws, sutures, plates and hooks, transfer the coracoacromial ligament by Weaver Dunn technique and the anatomical reconstruction of the ligament using grafts. In the Weaver Dunn technique, the stabilization of acromioclavicular joint is based on the removal of intact coracoacromial ligament which is attached to the acromion, followed by their direct fixing to the structure of the clavicle. In a next step, suture slings are made connecting the coracoid process to the clavicle, in order to replace the coracoclavicular ligaments [3].

The purpose of this work is to evaluate the behavior of the stabilization of the acromioclavicular joint made by Weaver Dunn technique in relation to the intacta acromioclavicular joint. For the analyzes three-dimensional finite element models are used. The motivation for this study is to add information and analysis on the treatment of acromioclavicular dislocation, providing new parameters to assist in choosing an appropriate surgical procedure.

2 MATERIALS AND METHODS

Three-dimensional models of the intact acromioclavicular joint and the surgical procedure of transfer of the coracoacromial ligament by Weaver Dunn technique are presented below.

2.1 Three-dimensional model of intact acromioclavicular joint

The three-dimensional model for the acromioclavicular joint without dislocation was formed by the clavicle, scapula and humerus, beyond the coracoclavicular, acromioclavicular and coracoclavicular ligaments, as shown in Figure1. The simplified geometry of the ligaments was designed in SolidWorks®, based on the dimensions of the insertion sites of each ligamentous structure to the bone.

2.2 Three-dimensional model of Weaver Dunn technique

In the representative three-dimensional model of the technique the same bony structures of the intact model were used. The geometry of the clavicle was sectioned at a distance of 2 cm from its distal end, where the transferred coracoacromial ligament was attached. Four holes were made on the clavicle for the passage of sutures that complement the procedure, substituting the injured coracoclavicular ligaments. The geometry of the suture was given in a simplified way of cylinders with a diameter of 0,5 mm. It presents a complete 3D model of

Weaver Dunn in Figure2. Table 1 shows the properties of each component models.

Figure 1: Three-dimensional model to simulate the intact acromioclavicular joint.

Figure 2: Three-dimensional model to simulate the Weaver Dunn technique.

Table 1: Properties of the materials of the component models.

Linear Elastic Materials			
Components	**Young's Modulus - *E* [MPa]**	**Poisson Ratio - *ν***	**References**
Clavicle	11000	0.3	[4]
Scapula	11000	0.3	
Humerus	11000	0.3	
Suture FiberWire® nº2	10729.4	0.4	[5];[6]
Material Hiperelástico			
Ligamentous	**Hyperelastic Constants– Ogden Model**		**References**
	μ_I	0.795870249	[7]
	α_I	25	
	D_I	0.259962666	

2.3 Mechanical contacts and boundary conditions

The contacts between the uninjured ligaments and bone structures were determined to be bonded, without taking into account the mechanical contact and considering the complete union of these components. The contact between the humerus and scapula was also considered bonded to represent the connection that glenohumeral ligament promotes between these bony structures. In surgical model, sutures were given as bonded to the clavicle and scapula because the modeling analyzes the time after the postoperative period, when the healing of the structure was completed. The mechanical property of the contact for the top face of the coracoacromial ligament transferred to the clavicle was also defined as bonded, considering that the ligament had a complete attachment to the bone.

Figures 3 (A) and 3 (B) shows the boundary conditions used in the simulation of the intact joint and the Weaver Dunn technique, respectively. In the simulations the proximal end of the clavicle was clamped in all directions, to represent the link with the sternum. Another condition adopted was the application of a force of 35 N on the scapula. This load represents the weight of the upper limb that is raised to its original position and fixed by sutures, which replace the coracoclavicular ligaments. Thus, this force would be like a pre-tensile load on the sutures. The load value used considered 20 N to the weight of the arm and 15 N to the weight of the forearm and the hand [8]. In addition, the sutures used in replacement of coracoclavicular ligaments were fixed on the two lateral directions, allowing the movement only in the direction of the tensile of the suture. A movement towards arm abduction was simulated by applying the displacement of 10 mm toward the local z axis of the humerus, at a point located at its end.

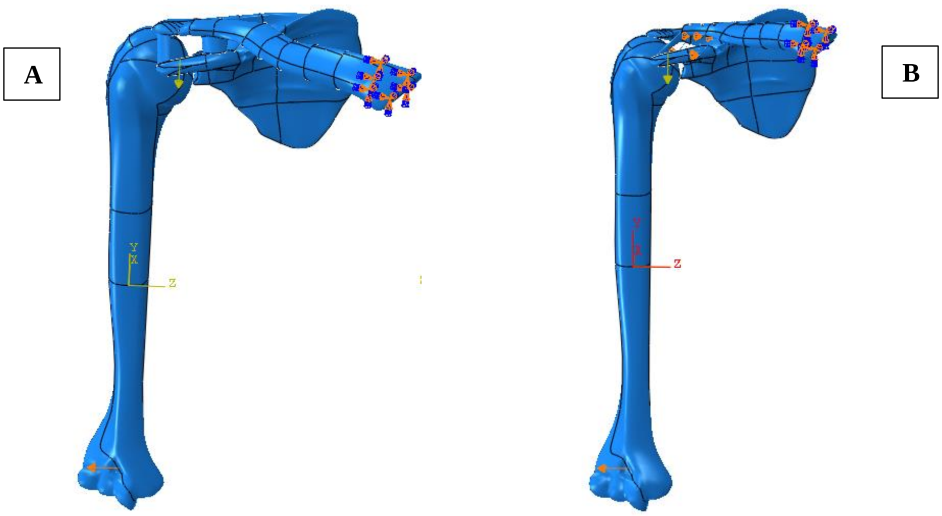

Figure 3: Boundary conditions applied to the models of surgical procedures. (A) Intact acromioclavicular joint, (B) Weaver Dunn technique.

3 RESULTS

The distribution of the total resulting displacement [mm] and the levels of von Mises stress [MPa] were evaluated for each model. The comparison between the original joint stability and the stability resulting after the surgical procedure was performed from the measurement of the distance between the coracoid process and the clavicle. The mesh convergence study was performed in numerical models analyzed.

3.1 Numerical analysis of the intact acromioclavicular joint

Analyzing the total displacements obtained in the model, larger displacement, 19.7 mm, was observed in the humerus. The scapula and clavicle showed maximum displacements of 6.74 mm and 0.76 mm, respectively. The resulting displacement on the clavicle is lower than that found in the other bony structures, because the end of the clavicle was fixed.

The maximum von Mises stress for the humerus was 0.77 MPa. The highest values were observed in the point where the displacement was applied and where contacts with the scapula existed. These maximum values occurred due to approximations and boundary conditions adopted in modeling and cannot be considered as representative for the general behavior of the component. It is noted that the highest stress values were found in the scapula at specific points, consisting of the application site load of 35 N and the point of contact with the humerus. Thus, it follows that the highest values were obtained near the regions of insertion sites of ligaments. The maximum stress values achieved in the bony structures are smaller than the yield strength of the cortical bone of 110 MPa [4], showing that the failure would not occur under these conditions.

Among the ligamentous structures of the model and the boundary conditions applied, the acromioclavicular ligament, responsible for primary restriction of the anterior and posterior translations of the clavicle, had the lowest maximum displacement of 0.8 mm, as can be seen in Figure 4 (A). The maximum von Mises stress of 46.38 MPa can be observed in Figure 4 (B). However, the maximum value was obtained at a specific region of the model and does not represent a real effect, resulting from imperfections in geometry or irregularities in the mesh generated.

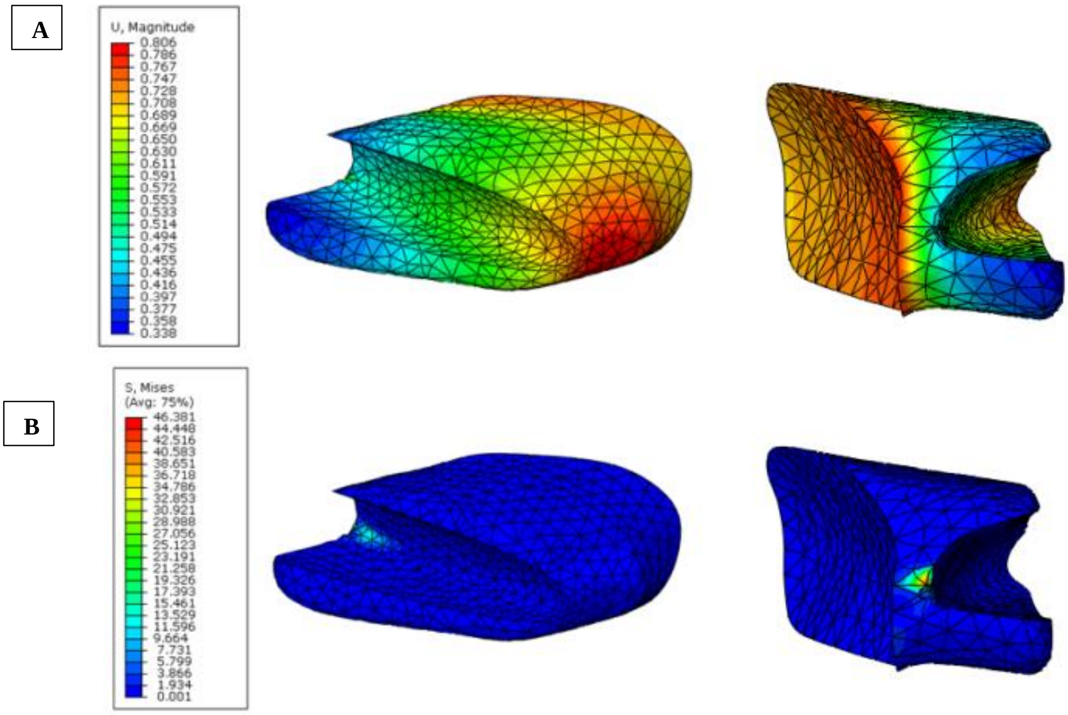

Figure 4: Gradients in acromioclavicular ligament. (A) Levels of resultant displacement [mm] (B) Levels of von Mises stress [MPa].

The coracoacromial ligament, responsible for limiting excessive upward movement of the humeral head, had 1.08 mm of maximum displacement, as shown in Figure 5. The maximum von Mises stress on the ligament was 0.05 MPa, as shown in Figure 6 (A). The maximum value was obtained in a concentrated region of the lower edge and to better visualize the distribution of the ligament stress throughout the range of values was modified. Thus, in Figure 6 (B) it is noticed that despite the higher stress concentration were located in the lower part of the component, there were also areas of concentration at the upper edge. In most cases, the coracoacromial ligament is ruptured in acromial insertion and in origin of the coracoid process [9].

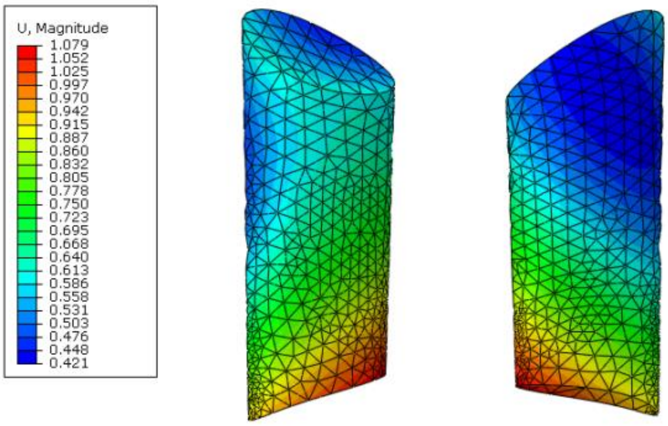

Figure 5: Distribution of displacement [mm] in coracoacromial ligament.

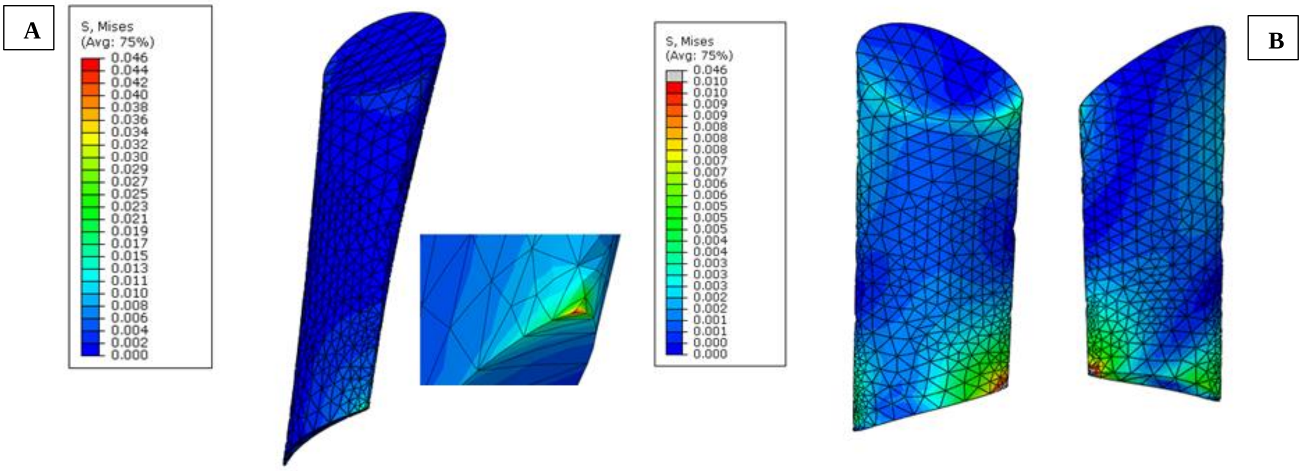

Figure 6: Distribution of stress levels [MPa] in the coracoacromial ligament. (A) Scale of original values. (B) Scale of modified values.

The conoid ligament is responsible for limiting the displacement in the upward direction. It had a maximum displacement of 1.95 mm, as can be seen in Figure 7 (A). Is possible to notice that the highest levels of displacement were obtained at the lower edge, where is the insertion site of the ligament in the scapula. Among the lateral regions of the ligament, it was observed that the right side had higher values compared to the left side. The gradient of von

Mises stress can be seen in Figure 7 (B), where we observed the largest stress value, 2.5 MPa, in the upper region of the ligament. In the lower region there are also local stress concentration, however, the levels found were lower. The failure of the conoid ligament usually happens in the top edge and in the inferior edge, which represent the clavicular insertion and the origin of the coracoid process, respectively [9].

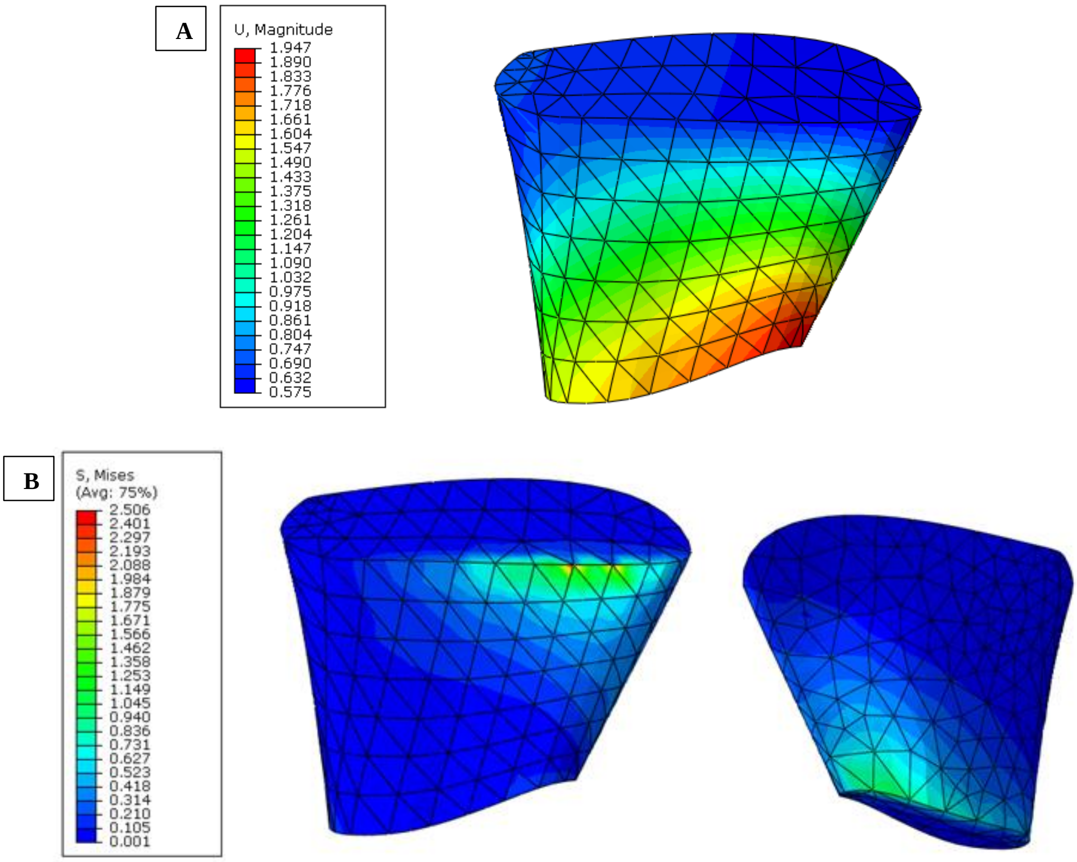

Figure 7: Gradients obtained in conoid ligament. (A) Levels of resultant displacement [mm]. (B) Levels of von Mises stress [MPa].

It was observed that the higher displacement of 1.96 mm was obtained in the trapezoid ligament, which has the purpose of ensuring the vertical stability of the joint. Figure 8 (A) shows the gradients of the levels of displacement. It is noted that the highest values of displacement are located on the right side of the structure and on its lower portion, where the ligament is inserted into the scapula. The trapezoid ligament also had higher levels of stress, especially in the upper and lower regions, as can be seen in Figure 8 (B).

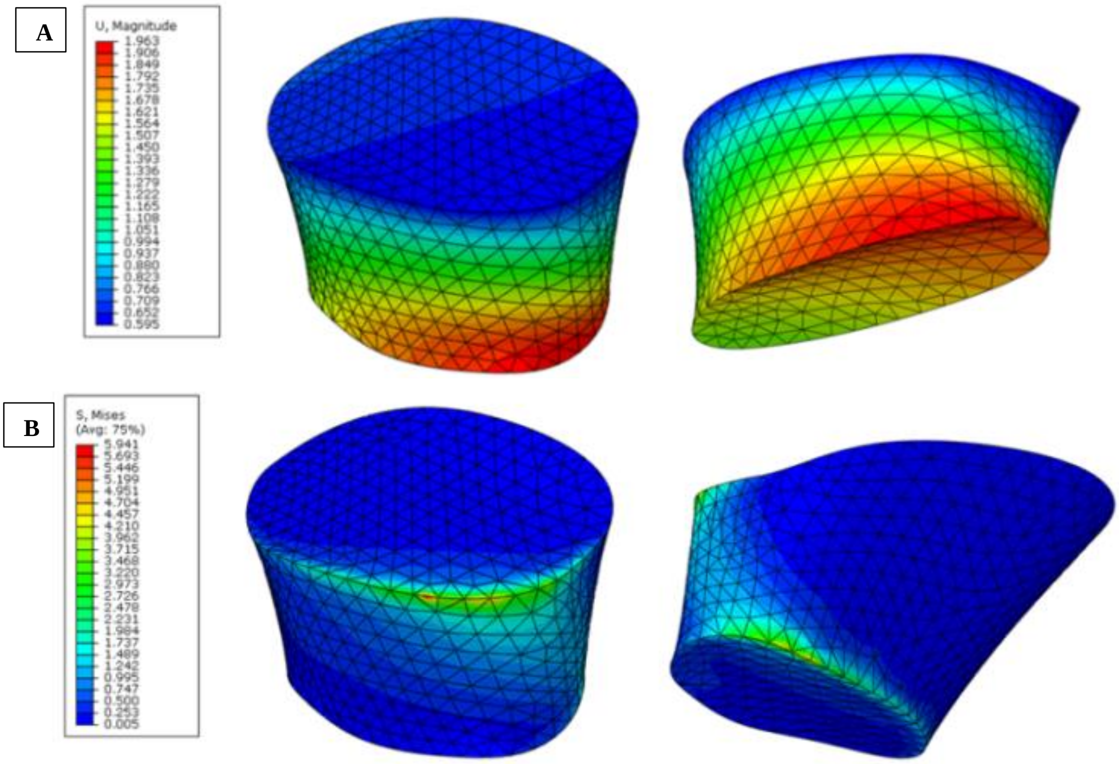

Figure 8: Gradients obtained in trapezoid ligament. (A) Levels of resultant displacement [mm]. (B) Levels of von Mises stress [MPa].

3.2 Numerical analysis of the surgical Weaver Dunn technique

In numerical simulations of the acromioclavicular joint repaired from Weaver Dunn technique was applied a displacement of 10 mm in the lateral direction of the humerus and a force of 35 N on the scapula to represent the weight of the upper limb. The clavicle was clamped at its end and sutures had their movements restricted in lateral directions. We observed the largest resultant displacement of 16.02 mm in the humerus, because the displacement was applied directly in this bone. The obtained maximum displacement to the scapula and clavicle were 4.82 mm and 0.01 mm, respectively. The displacement on the clavicle was lower than that found in other bony structures due to the boundary conditions assigned to the clavicle.

The humerus had a value of maximum von Mises stress of 0.58 MPa. A maximum stress of 167.69 MPa was observed to the clavicle. The high stress levels occurred in the clavicle holes through which sutures are passed because they are sites of stress concentration. The maximum stress found in the scapula was 670.49 MPa. The highest stresses obtained in the scapula are in the coracoid process, where the suture is passed and where the load is applied, and in the contact region with the humerus. Based on the analyzes it is noticed that the maximum stress values achieved in the bony structures are smaller than the yield strength of the cortical bone, 110 MPa, showing that the failure would not occur under these conditions.

The coracoacromial ligament transferred to the clavicle had maximum resultant displacement of 0.73 mm, located on its lower edge, as can be seen in Figure 9 (A). The von Mises stress had its maximum value of 0.32 MPa, also on the lower edge, shown in Figure 9 (B). In the proposed conditions, the ligament has reached a maximum stress value smaller than the maximum failure stress, which is approximately 20 MPa. Thus, it can be seen that the ligament would not be injured.

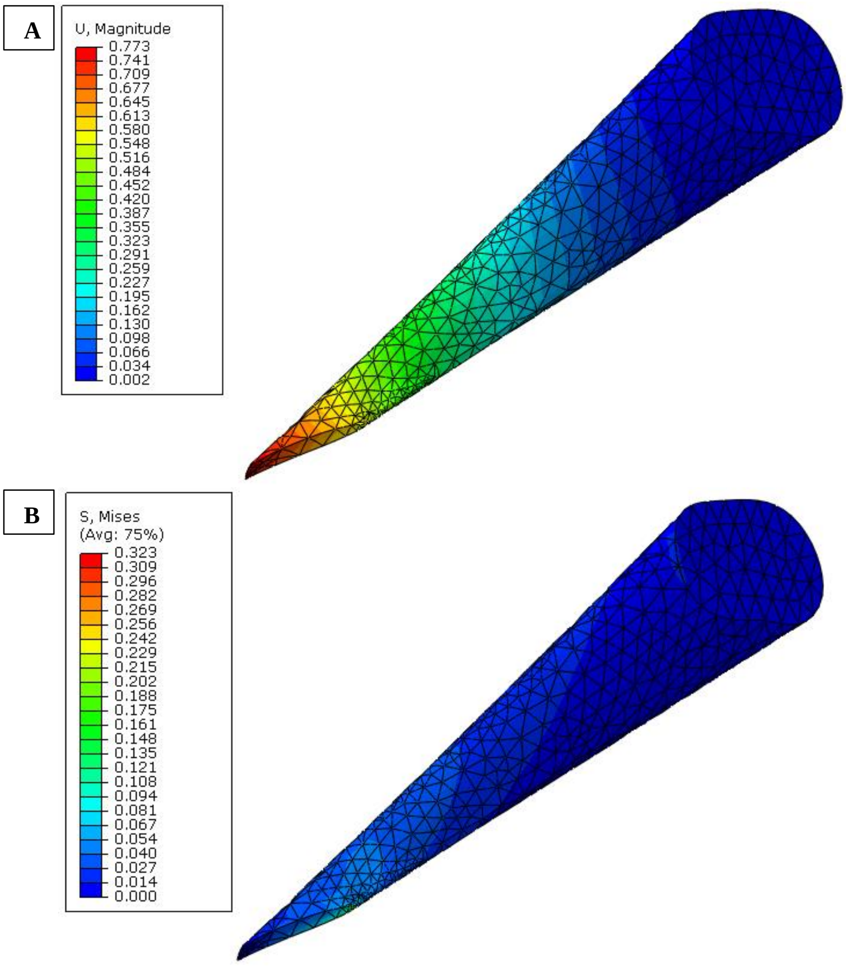

Figure 9: Gradients obtained in transferred coracoacromial ligament. (A) Levels of resultant displacement [mm]. (B) Levels of von Mises stress [MPa].

For sutures, the maximum displacement were 0.25 mm and 0.26 mm, located in the region passing under the coracoid process, as can be seen in Figure 10 (A) and 10 (B). The maximum stress values were observed in specific regions of the sutures, where the stress concentration occurred due to the existence of edges on the geometry, as can be seen in Figure 11 (A) and 11 (B).

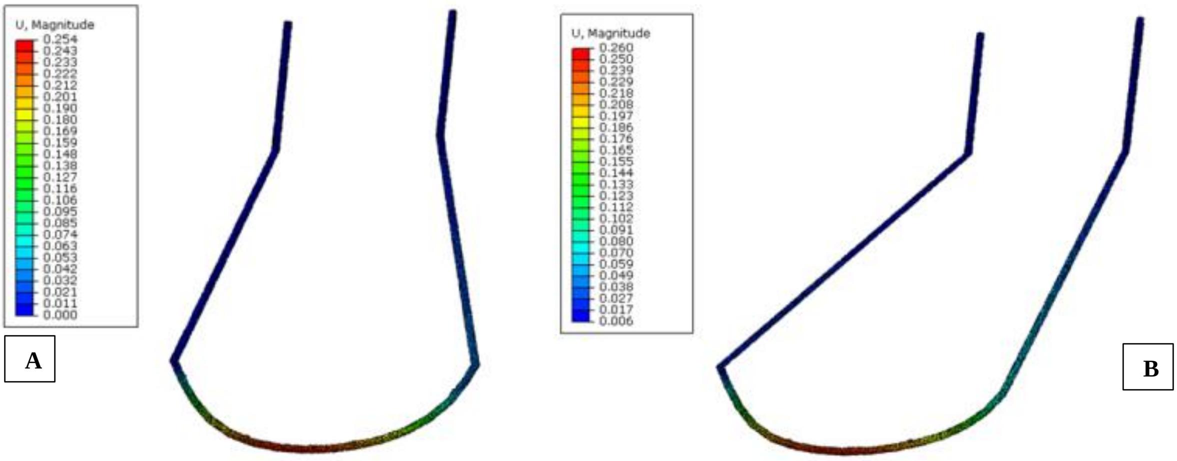

Figure 10: Gradients of resultant displacement [mm] for sutures. (A) Suture 1 (B) Suture 2.

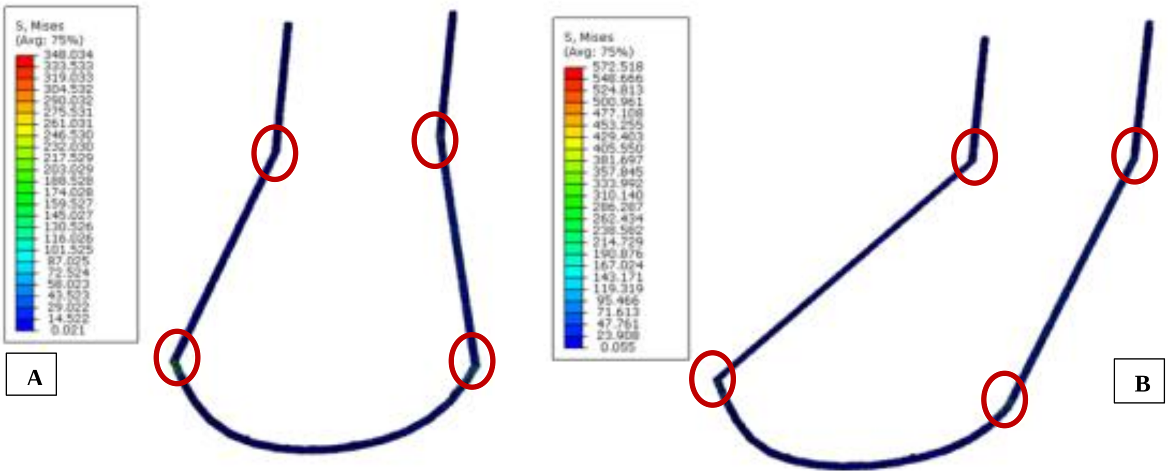

Figure 11: Gradients of von Mises stress [MPa] for sutures. (A) Suture 1 (B) Suture 2.

3.3 Evaluation of the stability of the Weaver Dunn technique

Patients who have suffered acromioclavicular dislocation and require surgical treatments perform radiographic assessments during the preoperative and postoperative period. With these X-rays is measured the distance between the clavicle and coracoid process. The distance is considered normal by orthopedic surgeons is approximately 12 mm [11]. In the two models was measured the distance between one point on the the clavicle and a point on the coracoid process, as shown in Figure 12. The distance found in the intact model was compared to the surgical template to note whether the Weaver Dunn technique ensures stability similar to the intact joint.

The distance measured in intact joints without applying the boundary conditions, was 9.90 mm. After application of the displacement, the distance increased to 10.31 mm and the surgical model was 10.18 mm. Therefore, it was found that the measured values between the clavicle and coracoid process in numerical models are close to the standard of approximately 12 mm, accepted by the medical community.

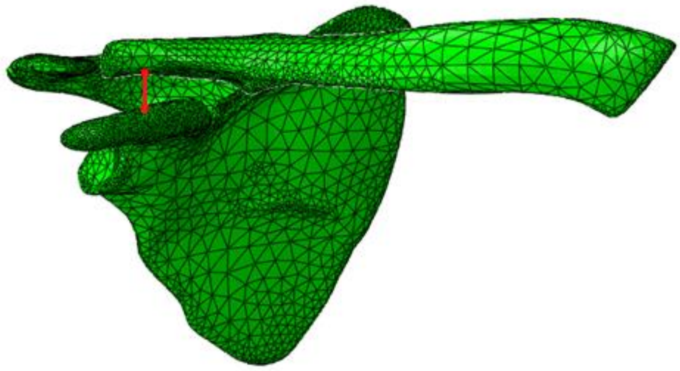

Figure 12: Points selected for measurement of distance between the clavicle and coracoid process.

4 CONCLUSIONS

The influence of the transfer of the coracoacromial ligament in surgical technique for stabilization of the acromioclavicular joint was assessed after suffering a dislocation. It was concluded that in the intact acromioclavicular joint to the proposed conditions, the trapezoid ligament showed higher levels of stress, followed by the conoid ligament, acromioclavicular and coracoacromial. The stress levels resulting in bone and ligamentous structures of the model did not exceed the limits of rupture, indicating that structural failure would not occur. It was also observed that each ligament stress levels obtained did not reach the maximum stress at rupture of approximately 20 MPa. Analyzing the coracoclavicular distances measured, it was concluded that the Weaver Dunn technique, to the proposed conditions, is effective in stabilizing the acromioclavicular dislocation.

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