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Original article

Understanding the causes behind coracoid graft osteolysıs in latarjet procedure (finite element analysis and comparison of three fixation methods)

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ABSTRACT

Background: Latarjet is one of the most common surgical procedure performed on patients with shoulder instability with osseous defects, some complications include coracoid bone graft osteolysis, osteoarthritis, graft detachment, and malpositioning were previously reported. Several studies investigated potential causes of graft osteolysis but still, it remains a crucial area of investigation. We aim to use finite element analysis to examine the potential correlations between three modes of fixation methods used in the Latarjet procedure (screw, wedge plate, and endobutton), and the coracoid graft osteolysis.
Hypothesis: Finite element analysis tested the hypothesis that there is a linear relationship between the compression stress on graft which was generated by fixation methods used in the latarjet and the coracoid graft osteolysis.
Material and methods: Boundary conditions and inhomogeneous material properties were carefully assigned within the material of the scapula and coracoid interface. For the screw and wedge plate fixations, an applied torque in the range of 1–1.5 Nm was used to characterize the surgeon's insertion torque during the surgical operation, while a 100 N compressive force was selected for the endobutton fixation.
Results: Relatively lesser stress magnitudes were observed with endobutton fixation method rather than screw and the wedge plate fixation. Statistical analyses revealed significant differences between the groups ($p < 0.05$).
Discussion: Excessive compressive stresses within the coracoid graft regions may be responsible for osteolysis due to negative effects over biological factors such as blood flow. Our study emphasizes the importance of taking into account the fixation method while performing the Latarjet procedure. We concluded that the mode of fixation used within the Latarjet procedure has a correlation on the coracoid graft osteolysis.
Level of evidence: I.

1. Introduction

Latarjet is the most commonly performed procedure for failed arthroscopic Bankart repair, and patients who had significant bone loss reaches > 20% of the glenoid surface [1]. After the original technique was described by Latarjet in 1954 [2], the technique was modified by Patte et al. in 1980 [3]. Di Giacomo et al. [4] used a mini wedge plate instead of screws. The arthroscopic Latarjet was introduced by Lafosse et al. [5], and recently Boileau et al. [6] proposed arthroscopic Latarjet with endobutton fixation.

Several complications such as graft osteolysis, non-union, and malpositioning regarding this technique have been reported previously [7–9]. Due to graft osteolysis screw head become proud and may cause anterior pain, tenderness and discomfort because of subscapularis irritation. Metal screw irritation may lead to humeral head cartilage damage and secondary operations needed for hardware removal [9].

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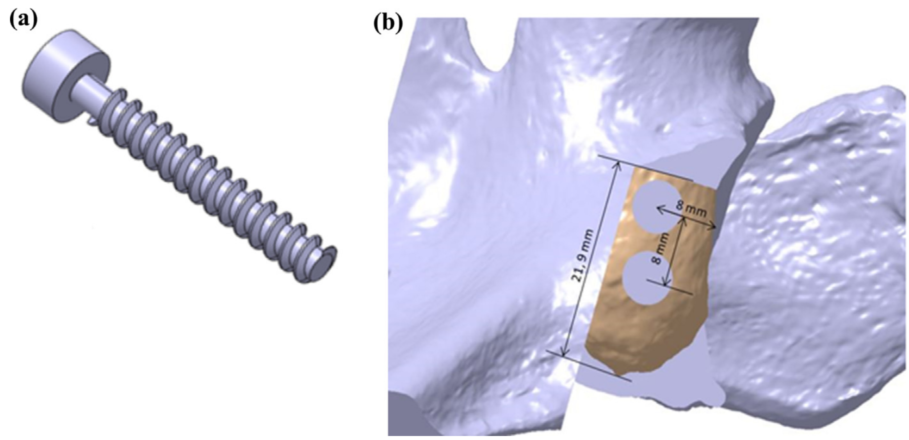

Fig. 1. a: the modeled cancellous screw and; b: the modeled positions of the screws.

There are many biological and biomechanical factors associated with osteolysis. From a biomechanical perspective, Wolff's law states that changes in the structure and function of bones, or only changes in function, were followed by changes in the internal structure and shape of the bone, under mathematical laws. Not only Wolff, but also Harold Frost [10] introduced the mechonostat theory regarding the existence of a homeostatic regulatory mechanism in bone, responsible for forming or resorbing bone in response to deviations in customary mechanical loading. Di Giacomo et al. [4] increased the compressive strength and provide a more rigid fixation between the coracoid graft and the glenoid neck, thereby reducing osteolysis. Their results revealed that there was no significant difference between mini-plate and screw fixation regarding graft osteolysis. Solely increased compression was not enough to achieve less osteolysis or more graft union. If biomechanical factors are one side of the coin, the other side is undoubtedly biological ones. The healing process between bone interfaces is associated with blood flow. Hamel et al. [11] reported that preservation of axillary artery branches, decortication of the glenoid anteroinferior neck and inferior part of coracoid process important for avoiding complications.

No studies in the literature neither in vivo nor in vitro compared the three different Latarjet techniques regarding coracoid graft osteolysis. In our study, relationships between the mode of fixation (screw, plate, and endobutton fixation) and graft osteolysis were investigated using Finite Element Analysis (FEA).

We hypothesized that there is a linear relationship between the compression stress on graft and graft osteolysis. The VMs distribution resulting from single endobutton fixation is the least and causes less osteolysis.

2. Materials and methods

2.1. Design parameters and functional requirements

3D solid model of the human scapula was obtained from computed tomography (CT) scan. Respective models of screws, wedge plate, and endobuttons were achieved by commercial solid modeling software (SolidWorks® from Dassault Systemes, Waltham, MA, US). The titanium screws® (from DePuy Synthes, Johnson&Johnson, Raynham, MA, US) were similar to commercial models, and they were 27 mm in length, fully threaded with base and crest diameters of 2.4 mm and 3.5 mm, respectively. 3D Computer-Aided Design (CAD) images of one of the screws and its placement were illustrated in Fig. 1a and b.

The design of the titanium mini wedge plate® (from Arthrex Inc. Naples, FL, US) were based on commercial model with a length of 16.5 mm, a width of 8.5 mm, and a height of 4.7 mm. The length of the spikes and diameter of the screw holes were taken as 2.4 mm and 4.8 mm (Fig. 2). For FEA, the thickness of the plate was maintained throughout the contact with the coracoid. The titanium round endobutton® and Suturefix® Ultra (from Smith and Nephew, Memphis, TN, US) was based on the commercial model and fixation shown in Fig. 3a and b.

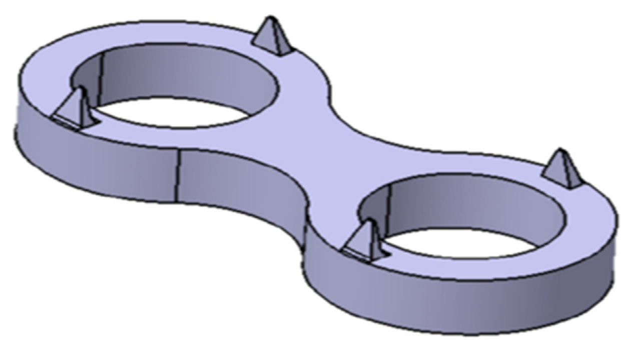

Fig. 2. The modeled wedge plate.

Data from the CT scans were processed using MIMICS 20.0® (from materialise, Leuven, BE) where additional features within the software allowed for the identification of the 3D coordinates and mass densities within the volume of the scan. Careful analysis of the data revealed an inhomogeneous distribution of the mass density within the volume of the scapula (Fig. 4) and inhomogeneous material properties of the sliced scapula (Fig. 5). Additional empirical relations [12] were used for the calculation of the local Young moduli, based on the estimated densities from the CT scan. It was beneficial from the Eq. (1) to quantify the Young moduli for each element of the scapula. The density distribution plays an important role regarding if it is decisive for Young moduli for the FEA.

$\rho \leq 1540\ kg/m^3$	$E(\rho) = 60 + 900\rho^2$	Eq. (1)
$1540\ kg/m^3 < \rho \leq 2000\ kg/m^3$	$E(\rho) = 90\rho^{7.4}$	

Further analysis using multipurpose mathematical software indicated an average distance to the nearest inhomogeneous neighbor at 0.78 ± 0.39 mm, whereas the boxed volume of the scapula was approximately $91 \times 63 \times 440\ mm^2$. The rationale behind the last calculation was to identify the smallest volume that we could slice the scapula into and yet, maintain an apparent density distribution that is identical to the one from the CT scan. The preview of the density distribution of the scapula after the material properties assignment was shown in Fig. 6.

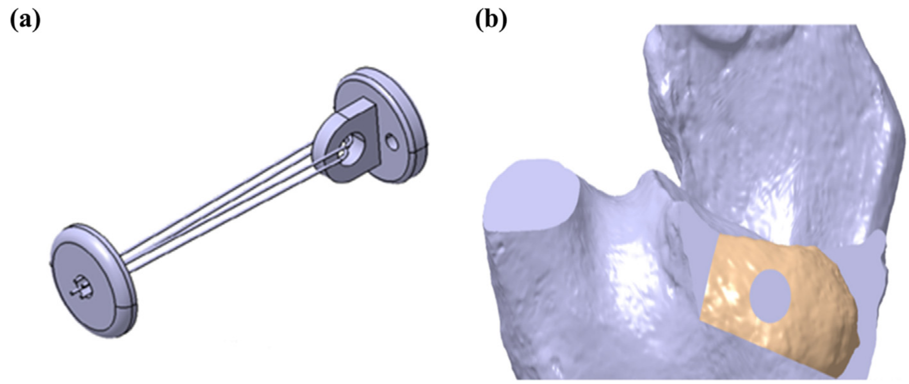

Fig. 3. a: the 3D model of the endobutton and; b: the 3D model of the endobutton fixation method.

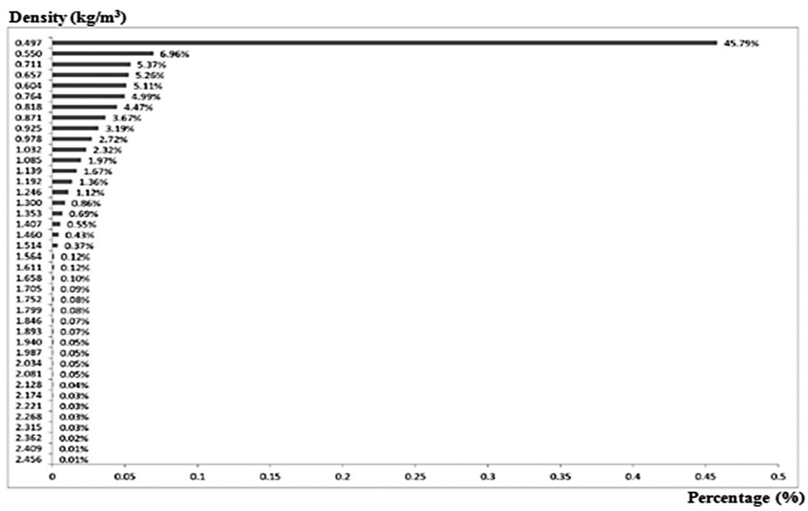

Fig. 4. Apparent density distribution of the scapula obtained from CT scan.

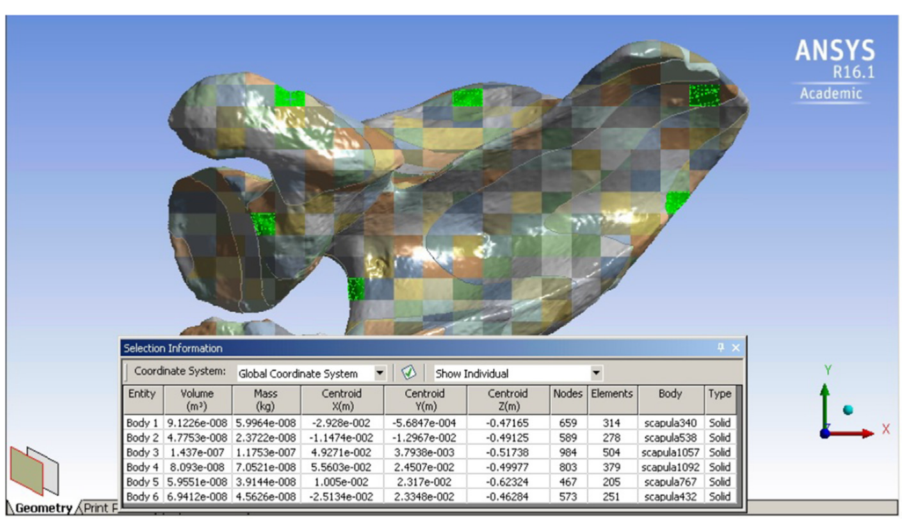

Fig. 5. The inhomogeneous material properties (density = mass/volume).

2.2. Finite element model

2.2.1. Material properties assignment

A self-developed program (Mathematica® from Wolfram Inc, Champaign, IL, US) sliced the volume of the scapula and coracoid, along with the principal directions for the frame of reference (XYZ), at an increment of 1.0 mm. Average material properties of each slice were then calculated based on the volume within the slice. Concurrent with these calculations, a CAD model of the scapula and coracoid assembly with the appointed mode of attachment (screw, wedge plate, and endobutton) was imported to the ANSYS 16.1® Workbench (from ANSYS Inc, Canonsburg, PA, US), where a self-developed program, using the scripting language of the ANSYS Design Modeler (DM), sliced the volumes of the scapula and

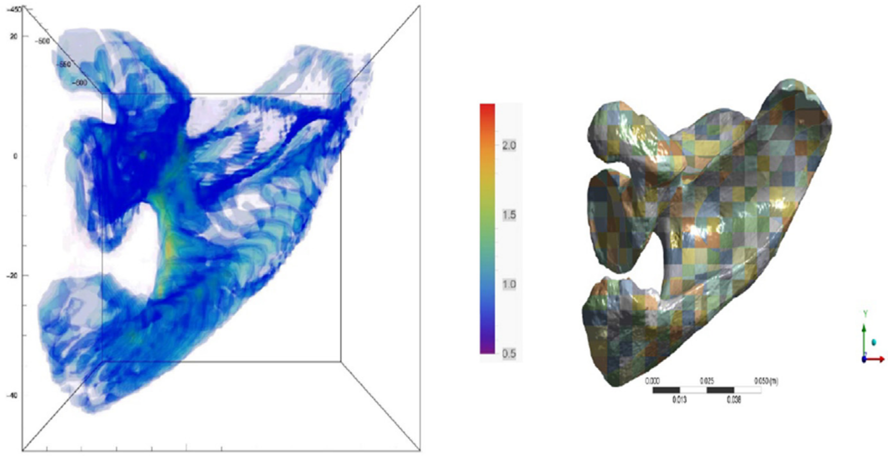

Fig. 6. Preview of the apparent density distribution.

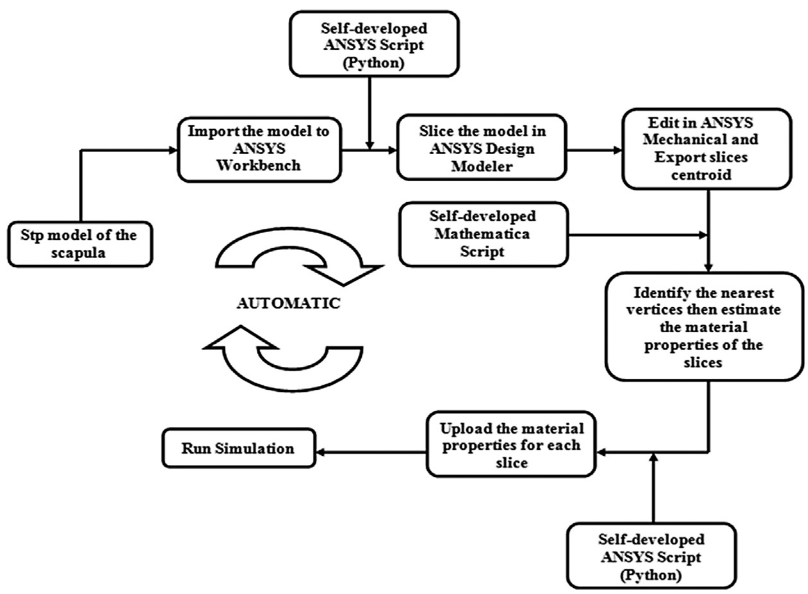

Fig. 7. Flowchart of the material properties assignment.

coracoid assembly using an identical scheme. Appropriate measures were taken to maintain consistency between the centroid of a slice in the ANSYS DM model tree and the matching slice from the multipurpose mathematical software. Another self-developed program using the script language of the ANSYS Workbench was used to create material assignments for each slice, and the properties included the mass density, Young modulus, and Poisson ratio.

The finite element modeling of the scapula and coracoid assembly was based on the homogeneous multi-layer model (HML), where constant material properties were assigned to each slice, and a homogeneous, isotropic, and linear elastic material behavior was assumed for the material of the slice. The overall computational slicing and material assignment process were summarized in Fig. 7 and a similar technique was used previously [13]. The material of the joint fixation (i.e., Titanium alloy Ti-6Al-4 V) was assumed to be homogeneous, isotropic, and linear elastic with a modulus of elasticity of 110 GPa and a Poisson's ratio of 0.3.

2.2.2. Meshing

Due to the complexity of the sliced scapula CAD model, the tetrahedral elements were used in this study. The mesh size was defined as 1 mm. Screws were not as complex as the sliced scapula. Therefore, the hexahedral elements were used for the screw. For high-quality results, the element size was improved for the screw region. The mesh size for the screw region was defined as 0.5 mm because the contact occurs in the screw region. The mesh size was also defined as 0.5 mm for the wedge plate and endobutton fixations.

2.2.3. Boundary conditions

Bonded boundary conditions were assumed between adjacent slices within the scapula and coracoid assembly, between the scapula and coracoid, as well as the coracoid and the appointed fixation. Physiological loading condition was used, whereby an applied torque in the range of 1–1.5 Nm [14,15] was used for screws and wedge plate fixations to simulate the surgeon's insertion torque during surgery. Meanwhile, a 100 N [16,17] compressive force was selected for the endobutton fixation. To avoid unnecessary CPU usage, a 3D model of the scapula was truncated halfway through its longest dimension, and the fixed support was applied through the truncated cross-section. The preliminary FEA results showed that the truncated part of the scapula did not affect the stress distribution.

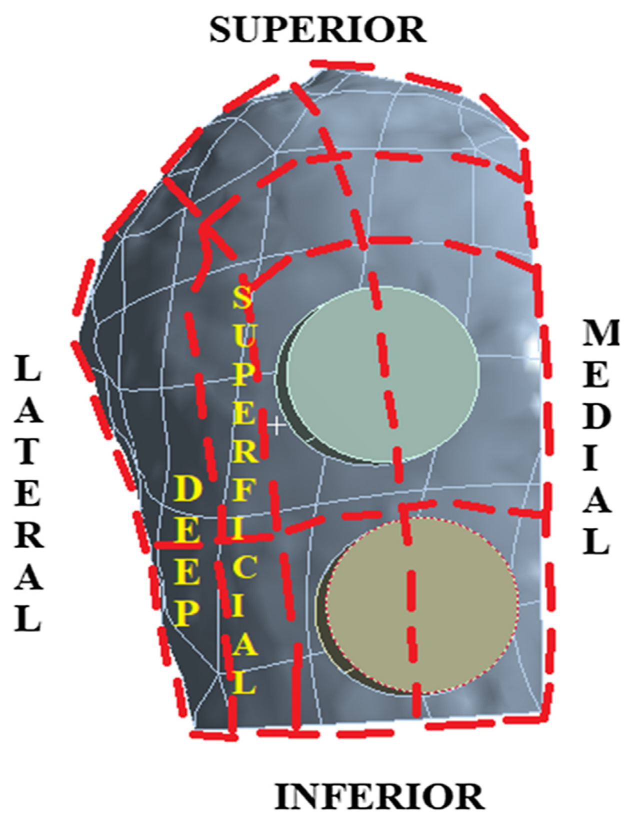

Fig. 8. *Distribution of 8 zones over the coracoid graft.*

2.3. Finite element analysis

The VMs was obtained by FEA for all three-fixation methods. The coracoid graft divided into eight zones (prox/sup/lateral – prox/sup/medial – prox/deep/lateral – prox/deep/med – dis/sup/lateral – dist/sup/med – dis/deep/lateral – dis/deep/med; Fig. 8) as conducted by Di Giacomo et al. [4]. The average VMs was calculated for each zone. The FEAs for all three cases were conducted via ANSYS 16.1, with the selected boundary conditions (Fig. 9). The results were given for the different views of the scapula for the straightforward interpretation of the stress distributions by zones.

2.4. Statistical analysis

Statistical analyses were performed using GraphPad Prism 8.0 for Windows (San Diego, CA, USA). One-way Anova followed by a Tukey multiple comparison test was conducted for the statistical comparison. A p-value lower than 0.05 was considered as statistically significant.

3. Results

The average VMs magnitudes of the eight zones that were given in Table 1 were obtained as 0.23125, 0.98750, and 0.59375 N/mm^2 for the endobutton, wedge plate, and the screw methods, respectively.

The one-way Anova test revealed statistically significant differences ($p < 0.0001$; Fig. 10). Regarding the Tukey multiple comparison tests, the endobutton fixation vs. wedge plate, the endobutton fixation vs. 2 screws fixation, and the wedge plate B vs. 2 screws fixation were statistically significant ($p < 0.05$).

Maximum WMs magnitudes were obtained at the location of the screw holes where the force and torque were applied. Additionally, higher VMs magnitudes were observed for the screw and the wedge plate fixation methods, when compared with the endobutton. It can be distinguished that higher VMs amounts were observed in the superficial and medial parts of the coracoid graft, for the screw and wedge plate fixation methods.

4. Discussion

Three different fixation methods (screws, mini-plate, and endobutton) were simulated by finite element analysis and the compression forces of these fixation methods on the coracoid graft were compared regarding osteolysis. Finite element analysis showed that all fixation types produced higher VMs around the implant and on the superior part of the coracoid graft. The lower part of the graft was subjected to less stress distribution in all simulations. The data we found was correlated with results of previously published articles [18,19]. Comparative analysis showed that endobutton fixation created less compressive force than mini-plate and screws, which confirmed our hypothesis.

As mentioned previously Di Giacomo et al. compared mini wedge plate versus two screws regarding osteolysis, and they did not observe any significant differences [4]. The VMs results of our study were similar to their study. Haeni et al. [18] found in their volumetric analysis that the superior half of the coracoid bone graft undergoes a significant amount of osteolysis at 6 months postoperatively. Zhu et al. proposed a new classification system regarding graft resorption by using an axial CT scan. The degree of graft resorption was 90.5% and more severe bone resorption seen around the superior screw [19]. Kee et al. evaluated 55 shoulders, they divided graft into superior, middle and inferior portions, and maximum osteolysis was observed in the superior third of the graft, followed by middle and distal third [20]. The results of our analysis also correlated with those studies.

In the literature high rate of non-union observed certain arthroscopic tecniques. Boileau et al. [21] reported a non-union rate of 20% and lysis of 7% in a series of 70 arthroscopic Bristow-Latarjet-Bankart repair. The unsatisfactory results in their bone healing rate might be related to using a single screw instead of 2 screws and using cannulated screws which have lower biomechanical properties than malleolar ones. In a 19 consecutive patient, Casabianca et al. [8] reported 22% graft healing problem.

There are several limitations to this study. Firstly, this is a computer-based basic-science research. Experimental reproduction of the fulfill Latarjet procedure would be extremely difficult. The aim was to evaluate the mode of fixation effect over coracoid and estimate if other factors are constant. Secondly, a single specimen was used for this study. However, scapula size and shape can vary considerably among individuals. Another limitation is we compare screws, mini-plate, and single endobutton fixation but not double ones. However, some surgeons like Philippe Valenti et al. [22] advocated that the use of double endobutton will prevent graft rotation, increasing compression will reduce graft osteolysis and non-union and increase graft healing.

The FEA study revealed that endobutton fixation generates less compressive forces on the coracoid graft. There has been only one paper published in the literature that compared arthroscopic Latarjet developed by Lafosse et al. [5] with endobutton fixation developed by Boileau [6] and open bone block surgery; however, that study did not made any comparision regarding graft osteolysis [23]. Future comparative clinical studies needed to evaluate coracoid graft osteolysis after Latarjet operation with using different fixation methods.

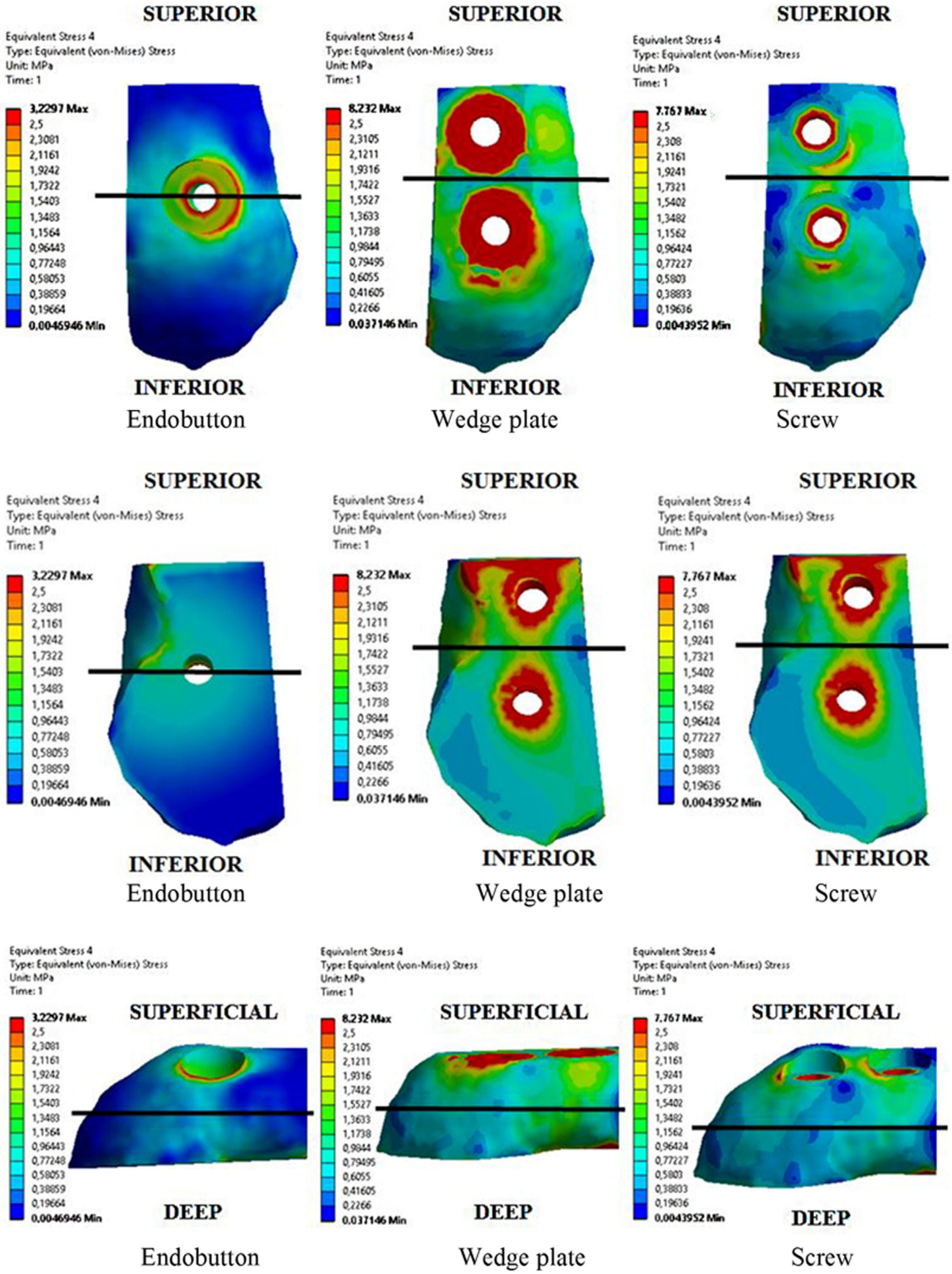

Fig. 9. Stress distribution of the fixation methods on the coracoid bone for endobutton, wedge plate, and screw.

Table 1
Regional average stress results of the coracoid bone (N/mm^2).

	Endobutton	Wedge plate	Screw
Superior			
Superficial			
Lateral	0.35	1.40	0.60
Medial	0.30	1.50	0.95
Deep			
Lateral	0.30	1.35	0.50
Medial	0.20	0.85	0.65
Inferior			
Superficial			
Lateral	0.30	0.50	0.50
Medial	0.15	1.00	0.75
Deep			
Lateral	0.15	0.60	0.45
Medial	0.10	0.45	0.35

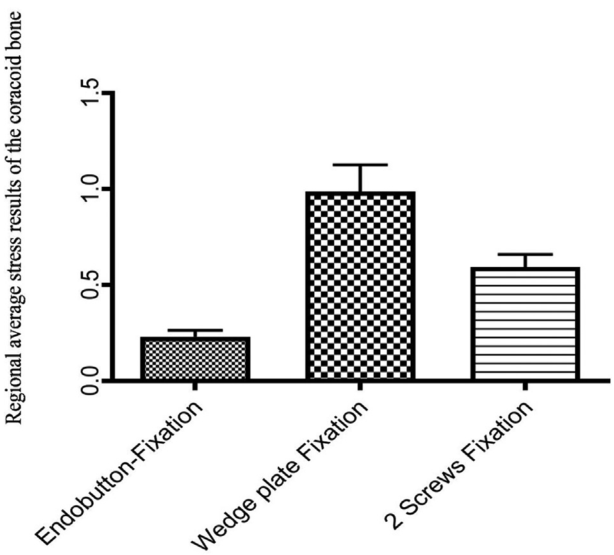

Fig. 10. Graph of statistical analysis of the study.

5. Conclusion

The mode of fixation used during the Latarjet procedure might have a direct impact on the coracoid bone graft osteolysis. The stress on the graft increases as the compression increases, due to fixation on the coracoid graft. The endobutton fixation creates a less compressive force on the graft than the other two methods. We think that this is important for graft osteolysis. Our study emphasizes the importance of taking the fixation method into account while performing the Latarjet operation.

Disclosure of interest

The authors declare that they have no competing of interests.

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Contribution

NBA conceived the study, participated medical part of finite element analysis, and drafted the manuscript.

OD, TGY, OCK, AAM, FK and MK participated in finite element analysis and helped to draft manuscript.

GA performed the statistical analysis.

All authors read and approved the final manuscript.

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