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Comparison of stress shielding between endobutton and screw fixation in the Latarjet procedure using three-dimensional finite element analysis

Seyyid Serif Unsal^{1*}, Tugrul Yildirim² and Ali Tecirli¹

Abstract

Background The Latarjet procedure is a well-established surgical technique for the treatment of recurrent anterior shoulder instability. Endobutton fixation systems have recently emerged as an alternative to conventional screw fixation, with the potential advantage of providing a more homogeneous stress distribution across the graft. The purpose of this study was to compare the distribution of Von Mises stress (VMS) in coracoid grafts fixed with screws versus endobuttons using three-dimensional finite element (FE) analysis.

Methods Three-dimensional FE models of the glenoid and coracoid graft were constructed using computed tomography data. Two fixation scenarios were evaluated: [1] Group A – fixation with two cortical screws, and [2] Group B – fixation with an Endobutton system. Identical graft dimensions, positions, and loading conditions were applied. A 50-N anteriorly directed force was applied at the graft–glenoid interface. Material properties were defined as homogeneous, isotropic, and linearly elastic. VMS values were calculated using Abaqus software.

Results Screw fixation produced localized stress concentrations around the screw holes with limited proximal load transfer, resulting in a heterogeneous graft stress pattern. In contrast, the Endobutton construct demonstrated a more uniform stress distribution across the graft. Although the screw group exhibited a higher mean von Mises stress (16.7 MPa [0.8–23.1]) compared with the Endobutton group (12.3 MPa [5.4–20.9]), a substantially greater proportion of graft volume exceeded the predefined high-stress threshold (≥ 15 MPa), indicating localized stress concentration. The Endobutton model showed fewer high-stress regions and improved stress homogeneity.

Conclusion Endobutton fixation in the Latarjet procedure results in a more uniform stress distribution across the coracoid graft than screw fixation, which may reduce the risk of graft osteolysis and enhance osteointegration. These findings warrant further validation with cadaveric and clinical studies.

Keywords Latarjet procedure, Endobutton fixation, Screw fixation, Finite element analysis, Von Mises stress, Graft osteolysis

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Introduction

The Latarjet procedure is a well-established surgical technique for the management of recurrent anterior shoulder instability, particularly in the presence of significant glenoid bone loss [1–3]. This procedure augments glenoid bone stock by transferring the coracoid process, thereby enhancing both static and dynamic stability of the shoulder [4]. Despite its effectiveness, graft-related complications such as resorption, displacement, or osteolysis remain relatively common and can adversely affect clinical outcomes [5]. Coracoid graft osteolysis and fibrous nonunions are considered the main causes of recurrent dislocation, pain, and stiffness following the Latarjet procedure [5].

Screw fixation has traditionally been the standard method for securing the coracoid graft. It provides greater initial rigidity and reduced graft displacement compared with endobutton fixation [6–8]. However, localized stress concentrations at the screw-bone interface can lead to stress shielding. This phenomenon may contribute to graft osteolysis, as described in previous biomechanical and finite element studies [5, 9].

In conjunction with arthroscopic techniques, endobutton fixation systems have recently been introduced as an alternative [10–13]. Unlike screws, Endobuttons distribute load more evenly across the graft, potentially improving both biomechanical stability and biological integration [14]. Although clinical studies have reported promising outcomes, finite element [FE]-based biomechanical evidence directly comparing the stress distribution patterns of screw and endobutton fixation in the Latarjet procedure remains limited.

Finite element analysis has emerged as a cornerstone in biomechanical research, offering a powerful computational approach to investigate complex mechanical behaviors within biological systems and medical devices [15]. Its application has been particularly transformative in orthopedic biomechanics, enabling the evaluation of novel implants, materials, and surgical techniques by simulating load transfer and stress distribution within bone-implant constructs [16, 17].

This study aimed to use three-dimensional finite element analysis to compare the stress shielding effects and biomechanical performance of Endobutton and screw fixation in the Latarjet procedure, with particular emphasis on load transfer mechanisms and potential implications for glenoid bone remodeling. We hypothesized that Endobutton fixation would result in more homogeneous stress distribution and higher stress in the proximal graft segment, thereby reducing the risk of graft osteolysis.

Materials and methods

Finite element model development

Three-dimensional models of the scapula, humerus, and coracoid process were reconstructed from computed tomography (CT) data acquired with a slice thickness of 0.1 mm. DICOM images were imported into 3D Slicer (version 5.6.2, www.slicer.org), where segmentation based on Hounsfield units was performed to generate three-dimensional bone geometries. The segmented models were exported in stereolithography (STL) format.

Surface refinement, reverse engineering, and computer-aided design (CAD) modeling of cortical and trabecular bone structures, as well as screw and Endobutton fixation components, were conducted using Altair Evolve (version 2023.1, Altair Engineering, Troy, MI, USA). The cortical shell thicknesses and internal trabecular volumes were defined according to anatomical references, and all components were positioned within a common three-dimensional coordinate system.

The prepared geometries were subsequently imported into Altair HyperMesh (version 2023.1, Altair Engineering) for preprocessing and mesh generation. All structures were discretized using three-dimensional first-order tetrahedral solid elements. Local mesh refinement was applied at implant–bone and graft–glenoid contact regions to improve stress accuracy and avoid numerical artifacts. Surface-to-surface contact definitions were assigned at all interacting interfaces to simulate realistic load transfer between fixation devices and bone. Node compatibility between adjacent meshes was ensured to enable proper force transmission.

Finite element analyses were performed using the Nastran-based implicit solver Altair OptiStruct (version 2023.1, Altair Engineering). Linear static analyses were conducted under predefined loading and boundary conditions. Post-processing and evaluation of von Mises stress distributions were carried out within the same solver environment. All computations were executed on HP workstations equipped with an Intel Xeon E-2286 processor (2.40 GHz) and 64 GB ECC memory.

A 25% glenoid defect was created parallel to the longitudinal axis of the glenoid, consistent with previous studies [9, 18] (Fig. 1). To simulate coracoid osteotomy, the distal aspect of the coracoid process was resected. The articular cartilage was modeled based on the external surface of the cortical bone, whereas the trabecular bone was modeled based on the internal surface of the cortical bone. According to prior reports, articular cartilage thickness was set at 2.0 mm for both the glenoid and the humeral head [9].

Simulation of coracoid transfer

To replicate the Latarjet procedure, the inferior portion of the coracoid process was repositioned onto the

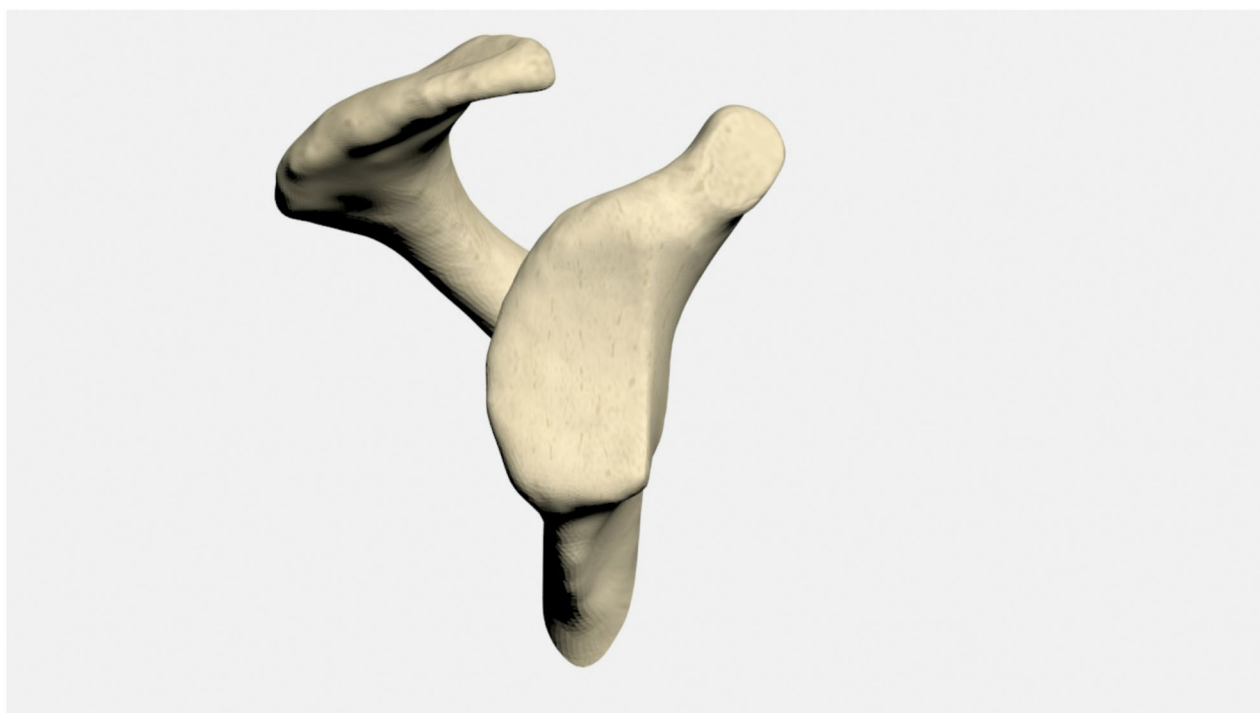


Fig. 1 25% glenoid defect model

anterior glenoid defect. Fixation of the coracoid process was achieved using either two semi-threaded titanium screws or a double-Endobutton construct, designed to replicate commercially available models (Fig. 2). The coracoid graft was positioned flush with the glenoid cartilage. Soft tissues were excluded from the simulation.

Arm positions

The initial finite element (FE) models were constructed with the arm in a neutral hanging position. To better illustrate the stress distribution pattern, 90° of shoulder abduction was subsequently simulated, in accordance with previous reports [9, 18] (Fig. 3). The center of rotation was defined at the humeral head, with abduction angles of 30° for the scapula and 60° for the humerus.

Material properties

All materials were assumed to be homogeneous, isotropic, and linearly elastic. Cortical and cancellous bone, titanium screws, and the Endobutton system were modeled with previously validated elastic modulus and Poisson's ratio values [9] (Table 1).

Boundary conditions

A compressive force of 50 N was applied to the glenoid region of the scapula via the humeral bone head. To replicate the tendinous pull, a 20-N force was applied from the apex of directed from the coracoid graft's apex towards the humerus (Fig. 4) [9, 18]. The models were stabilized

by restricting all degrees of freedom at the nodal points located in the distal portions of the humeral cortical and trabecular bone, as well as the medial aspect of the scapula's cortical and trabecular bone. Soft tissues, including the capsule, labrum, and muscles, were excluded to isolate the mechanical contribution of the fixation constructs and to avoid additional uncertainty associated with nonlinear material properties and complex contact definitions. Furthermore, static linear loading was used to represent the immediate postoperative mechanical environment (T0).

Two screws and one Endobutton construct were used in each respective fixation scenario. In the screw fixation model, preload was simulated by applying a tightening torque of 1–1.5 Nm, reflecting typical intraoperative conditions. The compressive force generated by the Endobutton was standardized at 100 N for simulation.

Quantitative stress analysis and data interpretation

Following completion of the finite element solutions, von Mises equivalent stress fields were computed for all models using the OptiStruct implicit solver (Altair Engineering, Troy, MI, USA), and stress distributions were evaluated both visually through contour plots and quantitatively through regional numerical analysis. To enable objective comparison of biomechanical performance between fixation techniques, each coracoid graft was anatomically subdivided into four predefined regions, defined as proximal-medial, proximal-lateral,

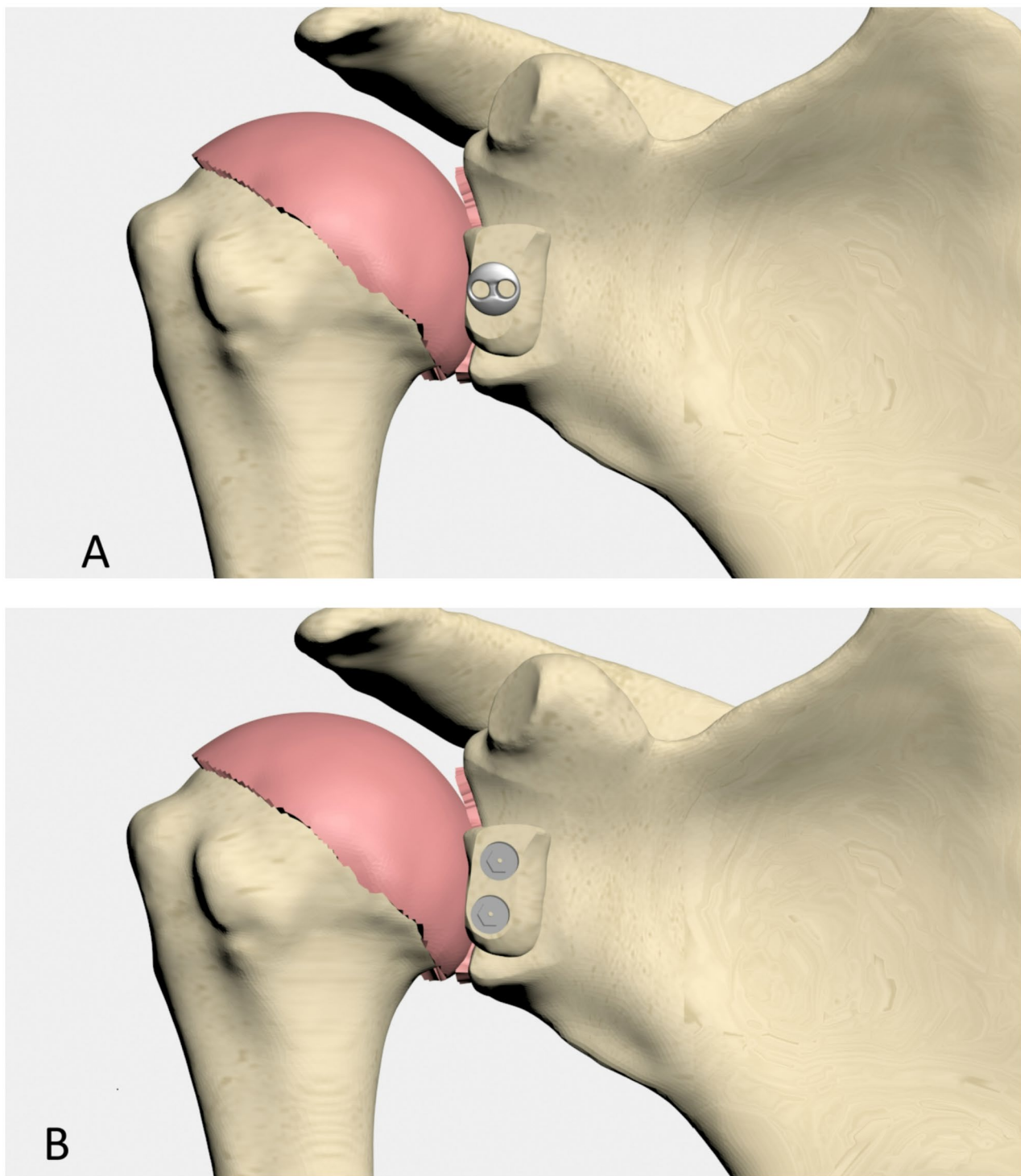


Fig. 2 Shoulder position in the neutral position used in the finite element model. **a** Endobutton fixation. **b** Screw fixation

distal-medial, and distal-lateral segments. All finite elements contained within each region were included in the calculations.

For each segment, regional stress values were extracted on an element-wise basis, and volume-weighted mean

von Mises stress, peak stress, and standard deviation were calculated. In addition, the coefficient of variation was determined to quantify the homogeneity of stress distribution within each region, with lower values indicating more uniform load transfer. To further

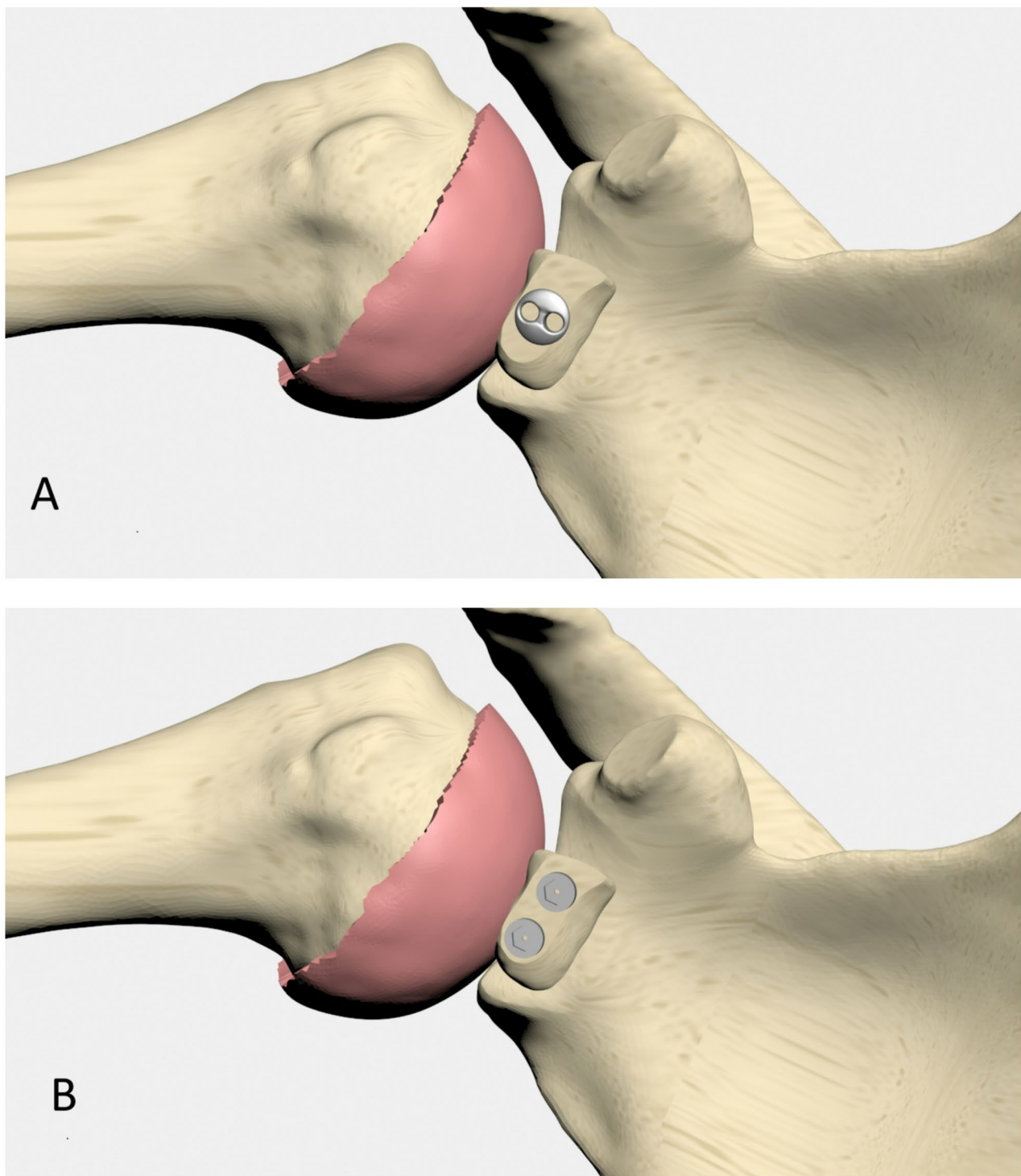


Fig. 3 Shoulder position at 90° abduction used in the finite element model. **a** Endobutton fixation. **b** Screw fixation

characterize stress shielding and local stress concentration, the proportion of graft volume exceeding a predefined high-stress threshold was evaluated. A threshold of 15 MPa was selected a priori to represent the upper physiological loading range of cancellous bone and to

approximate the mean stress observed in the screw fixation group, thereby allowing discrimination of localized stress concentrations. Proximal-to-distal stress ratios were also calculated to assess regional load transfer.

Table 1 Material properties

Material	Elastic modulus [MPa]	Poisson ratio
Humerus cortical bone	13,400	0.3
Humerus trabecular bone	2000	0.3
Scapula cortical bone	10,000	0.3
Scapula trabecular bone	1000	0.4
Titanium	113,800	0.3
Tendon	35	0.49

Comparisons between screw and Endobutton fixation constructs were performed region-by-region using these quantitative parameters. Differences were reported as both absolute values and relative percentage changes. Normality of the data was assessed prior to statistical testing, and regional stress metrics were compared using independent-sample Student's *t*-tests or Mann–Whitney *U* tests as appropriate, with statistical significance defined as $p < 0.05$. Statistical analyses were performed using SPSS software (version 26.0; IBM Corp., Armonk, NY, USA).

To ensure numerical stability and reliability of the results, mesh convergence analysis was conducted by progressively refining element size until variation in peak stress values between successive meshes was less than 5%, thereby confirming mesh-independent solutions. This standardized quantitative workflow allowed reproducible and statistically supported comparison of stress fields between fixation techniques rather than relying solely on qualitative visualization.

Results

Distinct differences in stress distribution patterns were observed between fixation techniques. In the screw fixation models, stresses were predominantly concentrated

around the screw–bone interfaces, with limited load transfer to the proximal graft segment, resulting in a heterogeneous stress profile. In contrast, the Endobutton constructs demonstrated a more evenly distributed stress pattern along the entire graft, including the proximal region (Fig. 5) (Table 2).

Quantitatively, the screw group exhibited a higher overall mean von Mises stress (16.7 MPa; range, 0.8–23.1 MPa) compared with the Endobutton group (12.3 MPa; range, 5.4–20.9 MPa) ($p < 0.05$). Peak stresses were localized near the screw insertion sites in the screw models, whereas stresses in the Endobutton models were more diffusely distributed across the graft surface.

Threshold-based analysis further demonstrated that a substantially larger proportion of graft volume in the screw group exceeded the predefined high-stress threshold (≥ 15 MPa), indicating focal stress concentration. In contrast, the Endobutton constructs showed fewer regions exceeding this threshold and lower regional stress variability, reflecting greater stress homogeneity across graft segments. Segmental analysis confirmed more consistent proximal-to-distal load sharing in the Endobutton group.

Discussion

To our knowledge, this study is the first to evaluate and compare stress distribution characteristics between Endobutton and screw fixation techniques in the context of the Latarjet procedure. The most notable finding was the more homogeneous stress distribution observed with Endobutton fixation compared with screw fixation. In the screw fixation group, stress shielding was evident in the proximal graft segment, consistent with previous findings reported by Sano et al. [18]. The observed differences in stress distribution between Endobutton and

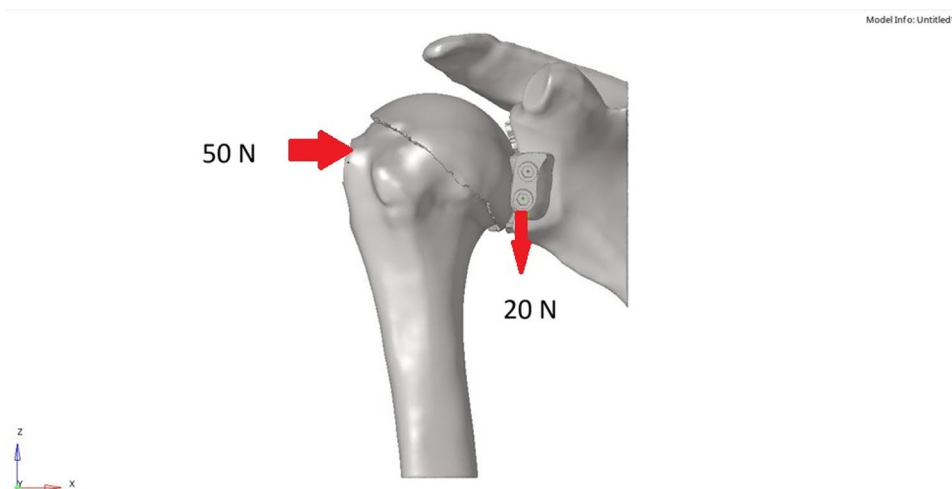


Fig. 4 Boundary Conditions. A compressive force of 50 N was applied to the glenoid region of the scapula via the humeral bone head and a 20-N force was applied from the apex of directed from the coracoid graft's apex towards the humerus

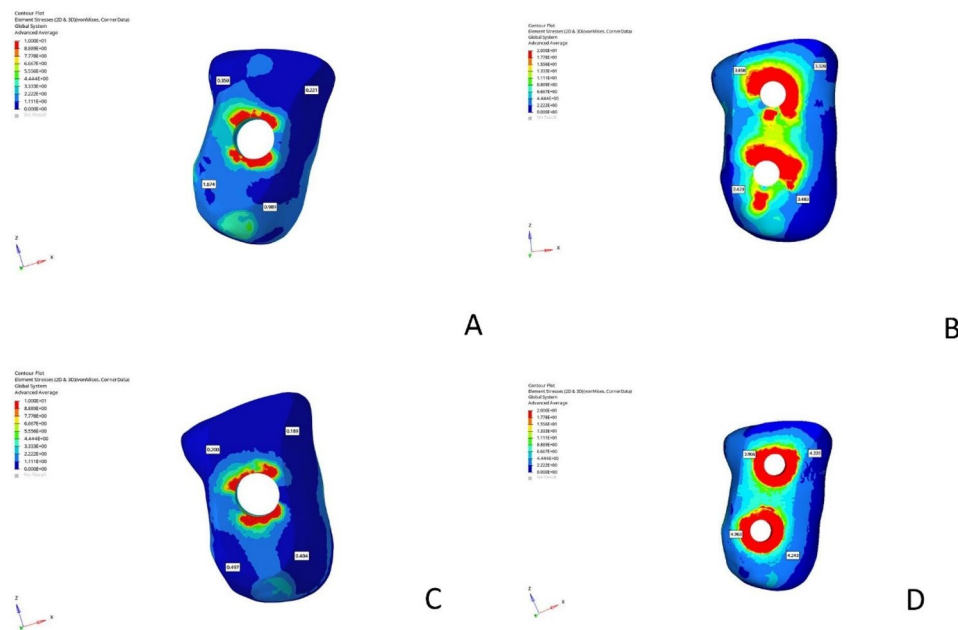


Fig. 5 Von Mises stress distribution in the coracoid graft for **A** 90° abduction position endobutton fixation **B** 90° abduction position screw fixation **C** Neutral position endobutton fixation **D** Neutral position screw fixation groups

Table 2 Von Mises Stress (VMS) Distribution According to Fixation Method

Fixation method	Stress distribution pattern	Mean VMS (MPa)	Maximum VMS (MPa)	Minimum VMS (MPa)	Proximal graft stress	Effect of 90° abduction
Screw fixation (Group A)	Stress concentration around screw holes; very low stress in proximal medial graft segment	16.7	23.1	0.8	Higher	Significantly increased VMS observed ($p < 0.05$)
Endobutton fixation (Group B)	More homogeneous stress distribution throughout the graft	12.3	20.9	5.4	Lower	Significantly increased VMS observed ($p < 0.05$)

VMS, Von Mises stress

screw fixation underscore the critical role of implant selection in mitigating stress shielding—a phenomenon in which relatively stiff implants bear a disproportionate share of physiological load, thereby reducing mechanical stimulation of adjacent bone and potentially promoting bone resorption. Our findings are also consistent with our previous finite element analysis comparing different coracoid graft orientations [9]. Although absolute stress magnitudes cannot be directly compared across studies because of differences in modeling assumptions, boundary conditions, and loading protocols, the present results remain within the same order of magnitude as previously published finite element analyses of Latarjet fixation constructs. Prior studies have reported graft stress values in the sub-MPa to low-MPa range under simplified loading conditions, whereas our model demonstrated higher stresses (approximately 12–17 MPa), likely reflecting differences in applied compression, contact definitions, and graft–implant interaction. Despite these numerical differences, both studies demonstrate similar stress distribution patterns, particularly greater stress concentration

around screw fixation and more homogeneous load sharing with Endobutton constructs, supporting the biomechanical plausibility of our findings [19].

Finite element analysis has increasingly become an indispensable tool in orthopedic biomechanics, enabling comprehensive evaluations of various fixation strategies and implant designs [20]. This computational approach offers a distinct advantage over traditional cadaveric studies by eliminating inter-specimen variability and allowing for precise control over loading conditions and material properties [21]. For instance, previous finite element studies have effectively compared the biomechanical performance of different fixation methods in distal femoral fractures and vertebral body replacements, providing valuable insights into optimal internal fixation strategies and the impact of fusion-bone stiffness on load distribution [22, 23].

Endobutton fixation may offer both biomechanical and biological advantages by distributing load more evenly along the entire graft. This more homogeneous stress transfer has been suggested to support osteointegration

while reducing stress shielding, a phenomenon commonly associated with rigid metallic fixation systems. Erickson et al. reported that, despite providing mechanical stability comparable to screw fixation, cortical button constructs demonstrated improved osteointegration potential, likely related to more physiological load sharing across the graft–bone interface [24]. In contrast, screw fixation tends to concentrate stress around the screw–bone interface, as observed in our finite element analysis. Although this localized stress concentration provides strong initial fixation, it may limit effective load transfer to the surrounding bone over time, potentially promoting stress shielding and subsequent bone resorption. Similar localized stress phenomena associated with rigid fixation have been described in previous biomechanical and clinical studies, where stress concentration around screw holes was linked to micromotion and adverse remodeling at the bone–implant interface [25, 26]. Williams et al. demonstrated that cortical button fixation exhibits lower resistance to direct graft loading compared with conventional screw fixation [6]. However, this reduced stiffness was accompanied by less iatrogenic damage to adjacent bone structures. In situations involving unexpected or excessive loading, these differences may influence early graft behavior, potentially increasing the risk of graft migration with button fixation while increasing the risk of local bone damage with screw fixation. Clinical outcome data further support this trade-off between fixation rigidity and biological tolerance. It was reported that lower recurrence rates with screw fixation but a higher incidence of reoperations related to hardware irritation and postoperative pain [27, 28]. Taken together, these findings suggest that optimal graft success depends not only on absolute fixation strength but also on physiological load distribution, which may play a key role in minimizing stress shielding and promoting long-term graft viability in glenoid bone augmentation procedures.

Limitations

This study was based on computational modeling and did not include cadaveric or clinical validation. Bone quality, soft tissue interactions, and dynamic shoulder motion were not simulated. In addition, the screw–bone interface was simplified, and individual screw thread geometry was not explicitly modeled, which may influence local stress concentrations at the implant–bone interface.

These factors may influence *in vivo* stress distribution and should be addressed in future investigations. Future studies should also incorporate patient-specific finite element modeling, as variations in bone morphology and density may substantially alter stress distribution patterns and potentially affect clinical outcomes.

Conclusion

This FE analysis demonstrated that Endobutton fixation provides a more uniform stress distribution across the coracoid graft compared with screw fixation in the Latarjet procedure. However, this advantage was observed primarily at the initial time point (T0) under static loading conditions. By reducing stress shielding in the proximal graft segment, Endobutton fixation may enhance osteointegration and decrease the risk of graft osteolysis. Further cadaveric and clinical studies are warranted to validate these findings.

Abbreviations

VMS	Von Mises stress
FE	Finite element
CT	Computed tomography

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Not applicable.

Author contributions

All authors have read and approved the final manuscript. Seyyid Serif Unsal and Tugrul Yildirim participated in the study design and conception. Seyyid Serif Unsal and Tugrul Yildirim conducted the study, data analysis, and manuscript drafting. Ali Tecirli prepared the figures and assisted in the literature review and manuscript revision. All authors read and approved the final manuscript.

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Data availability

The data underlying the current study will be shared by the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

The study was conducted in accordance with the Declaration of Helsinki (1964) and its later amendments. The acquisition and use of CT images were approved by the Clinical Research Ethics Committee of SBU Kanuni Training and Research Hospital, Trabzon, Turkey (Approval/Decision No: 2022/41; Application No: 11444; Date: 18.07.2022), and written informed consent was obtained from all volunteers. Clinical trial number: not applicable.

Consent for publication

The patients enrolled in the study agreed to the use of the data for research and to authorize its publication.

Competing interests

The authors declare no competing interests.

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