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Load transfer after cemented total shoulder arthroplasty

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Background: Glenoid loosening is the primary reason for failure after a total shoulder arthroplasty (TSA), but the failure mechanism is not yet known. This study determined how the load transfer and stress distribution are affected by the introduction of a glenoid implant.
Methods: We developed a finite-element model of a scapula with and without a virtually implanted modern glenoid prosthesis design. Two load magnitudes were considered: normal and high. Loading locations were simulated at the center and at 4 eccentric positions on the glenoid. A metal-backed implant was also simulated to understand the effect of fixation stiffness.
Results: In the intact glenoid, for both center and eccentric loading, the majority of stress was distributed in the cancellous bone, whereas after a reconstruction, stresses in that region were lower. Metal-backed implants further decreased the joint load carried by the bone. Stresses in the cement layer increased during eccentric and high-magnitude loading.
Conclusion: This study provided a basic understanding of the load-sharing phenomenon after a TSA that could explain glenoid loosening failure. Our results suggest that with reconstruction of the glenoid with a contemporary implant, the load transfer pattern is significantly altered, with eccentric and high-magnitude loads increasing stresses in the cement indicating potential for failure. The use of a metal-backed implant reduces the load carried by the bone, which may be detrimental to long-term TSA survival.
Level of evidence: Basic Science, Computer Modeling, Finite-Element Analysis.

Keywords: Total shoulder arthroplasty; glenoid loosening; load transfer; finite-element analysis; eccentric loading; stress distribution

Glenoid loosening is the primary reason for failure after a total shoulder arthroplasty (TSA), accounting for 32% of complications after surgery.[5,45] The ‘‘rocking-horse’’ phenomenon induced by eccentric loading is commonly attributed to loosening of the glenoid component as it causes compressive stresses at the fixation surface when the external load is applied at the superior or inferior edge of the glenoid component, as well as tensile stresses on the opposite end.[12,45] However, how this phenomenon affects the mechanics of a bone-implant system and, in turn, affects failure remains unclear. Existing theories are conflicting, suggesting that failure occurs in the bone, in the cement, or at the interface, with no agreement on the mechanism that causes glenoid loosening.[22,24,28,43,46]

This lack of consensus is in large part responsible for the broad array of glenoid implant designs that have been developed in an effort to decrease the rate of loosening. Keels and pegs are commonly used as fixation features, and for some designs, a metal backing is incorporated to supplement fixation between the implant and the bone with or

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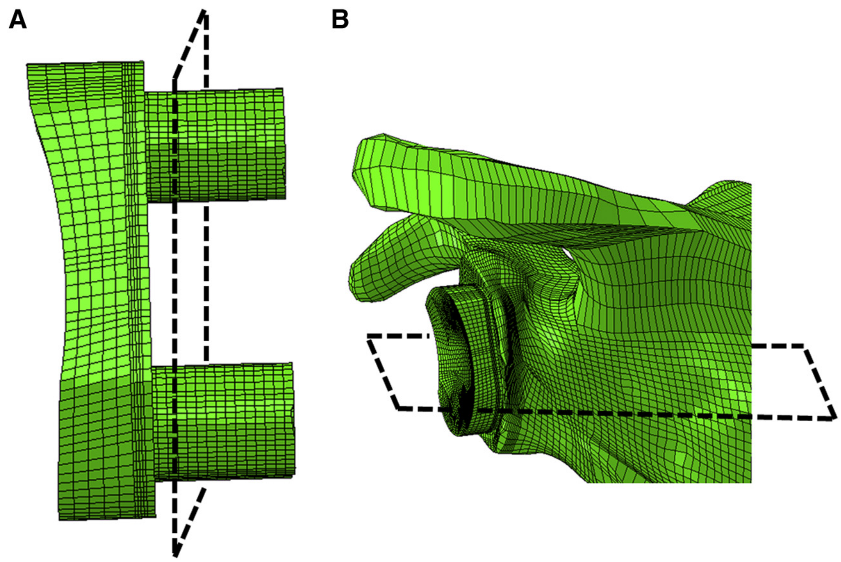

Figure 1 (**A**) Posterior view of glenoid implant and cement. The *dashed plane* shows a representative coronal layer used to analyze the load carried by the bone, cement, and implant. (**B**) Posterior view of scapula, showing insertion of glenoid implant. The *dashed plane* shows a representative transverse cross section used in the analysis.

without the use of cement. Non–metal-backed designs have a greater survival rate than metal-backed designs, and pegged designs have a lower incidence of radiolucency than keeled designs.[6,9,33,40,41] Although better fixation has been suggested with cemented and pegged implants, the rate of radiolucencies is still as high as 36% to 83% with these commonly used designs, consistent with high aseptic loosening rates.[33,46]

Although considerable effort has gone into glenoid implant design based on local stress distributions, little understanding exists of the global load transfer patterns that influence local stresses. Previous studies focused on how variables such as cement mantle thickness, loading position, or implant design altered the local stresses in the cement, in the surrounding bone, or at fixation interfaces.[7,43] Such parametric analyses have the advantage of focusing the effects of each parameter on local stress distributions. However, global load redistributions affect the local stresses that lead to failure. Exploring load transfer was successful in developing solutions to early failures in hip and knee replacement by elucidating the factors contributing to implant failure.[1,3,8,18,20,23,26] Finite-element (FE) models determined, at a system level, the redistribution of joint load in the surrounding bone after implantation.[10,14,17,20,23,26]

Before the failure mechanism in the glenoid can be determined, it is first necessary to gain an understanding of the load transfer through the glenoid before and after reconstruction, similar to hip and knee studies. We developed a FE model of a scapula with and without a virtually implanted modern glenoid prosthesis design to determine how load transfer and stress distribution are affected by the introduction of a glenoid implant, by physiological alterations in the location and magnitude of the joint load on the glenoid, and by the presence of a metal backing.

Materials and methods

Study design

The 3-dimensional geometry of an intact scapula was created based on computed tomography (CT) scans of a left cadaveric shoulder. A commercially available cemented and pegged polyethylene glenoid prosthesis was implanted simulating a TSA. Details are provided later in this report; in brief, 2 load magnitudes were considered: normal and high. Loading locations were simulated at the center and at 4 eccentric positions on the glenoid surface. The load carried by the bone, cement, and implant, as well as the local stresses generated in the cement layer and glenoid, were determined and compared among the loading scenarios.

FE model

The left scapula of a cadaver (93-year-old white woman) with no apparent pathology underwent CT scanning at 1-mm intervals in the transverse plane. The 3-dimensional geometry of the scapula was developed from the scans using Mimics software (version 12.0; Materialise NV, Leuven, Belgium). Two models were created: an intact scapula and a reconstructed scapula with a virtually implanted glenoid prosthesis. In the latter model, only the face of the glenoid was reamed to match the flat-backed geometry of the back of the prosthesis. The prosthesis was virtually implanted to re-create the native version, which is neutral to the long axis of the scapular body according to recommendations from a surgeon. The prosthesis (Comprehensive; Biomet, Warsaw, IN, USA) was a 3-pegged, asymmetric, all-polyethylene, cemented implant with a radius of curvature of 38.1 mm and was surrounded in the model by a uniform 1-mm cement layer (Fig. 1, *A*). The pegs were modeled as cylindrical rods 10 mm in length. To model a metal-backed prosthesis, the cement material was given metallic properties as described later.