INTRODUCTION: In patients with cuff tear arthropathy, loosening of a glenoid component is a common problem after total shoulder arthroplasty (TSA). In such condition, finite element (FE) analysis will be useful to investigate stresses on implants and bones. Since soft tissue plays an important role in stabilizing a shoulder joint, load by muscle forces will greatly affect the result of analyses. However, most of the previous FE model of TSA simulated a shoulder with normal cuff function, and there is no study which precisely investigated loading conditions of massive rotator cuff tear shoulders. We have developed a numerical model for simulating shoulder muscle forces in various conditions [1]. The purposes of this study were to create a three-dimensional (3-D) FE model of TSA, to apply shoulder muscle forces of normal and cuff tear shoulders which were calculated by the numerical analysis as loading conditions, and to compare the results of normal and cuff tear shoulders.

METHODS: Bone geometry of scapula and humerus was created from CT data of a normal volunteer (23 years old, male). Three-dimensional reconstruction of the CT data was performed in ANALYZE (Biomedical Imaging Resource, Rochester, MN) and was transferred to ANSYS (Ansys, Inc., Canonsburg, PA) as CAD data. A keel-type glenoid component (UHMWPE) and a humeral component (head; alumina ceramic, stem; titanium alloy) were implanted into the bone and a bone cement layer of 1 mm thickness was added beneath the glenoid component (Figure 1). Models of both the present glenoid component and the new component, which has hood in the superior part to prevent upper migration of the humeral head, were created (Figure 2). Each material property was taken from the previous study [2]. The model consisted of about 25000 8-noded structural elements. The medial edge of the scapula was constrained in all directions. The glenohumeral joint consisted of about 25000 8-noded structural elements. The medial edge of the scapula was constrained in all directions. The glenohumeral joint was positioned in 60 degree abduction. Contact analysis was done by creating a contact pair between the surface of the humeral head and the inferior part of the scapula. As loading conditions, 7 muscle forces (anterior, middle, and posterior deltoid, supraspinatus, infraspinatus, subscapularis, and teres minor) were obtained by the numerical analysis previously reported by the authors [1] and loaded on the insertion point of each muscle. Normal shoulder and massive rotator cuff tear (supraspinatus and infraspinatus tear) shoulder were simulated. The stresses of the model were evaluated with von Mises’ stress of the glenoid component and the cement layer. The stresses were compared between normal and massive cuff tear shoulders, and the new component was evaluated.

RESULTS: 1. Stress distribution of the glenoid component (Figure 3): In the normal shoulder (a), high stress (1.34 MPa) was observed in the superior part of the component. In the cuff tear shoulder (b), high stress area shifted postero-superior and the maximum stress increased to 1.78 MPa. In the new component (c), maximum stress of 3.91 MPa was observed at the base of the hood. 2. Stress distribution of the cement layer (Figure 4): The normal shoulder (a) showed high stress (3.91 MPa) in the superior part of the cement layer. The high stress area shifted superior and the maximum stress increased to 5.60 MPa in the cuff tear shoulder (b). In the new component (c), the high stress concentration in the superior part disappeared and the maximum stress decreased to 3.56 MPa.


Figure 1: FE model of the glenoid and humerus.

Figure 2: Glenoid components for the FE model. Left: a present component, right: a new component.

Figure 3: Stress distribution of the glenoid component.

Figure 4: Stress distribution of the cement layer.

DISCUSSION: There are only few studies of FE analysis which employ loading conditions of rotator cuff tear shoulders [2] [3]. And, even in those studies, direct loads were applied on the glenoid component and only the direction or the loading point was changed. Though the importance of loading muscle forces in analysis of the cement layer was reported [4], there has been no FE analysis in which individual muscle forces in a cuff tear shoulder were loaded. In the current study, not only scapula but humerus were included in the model, and the forces of the muscles attaching the humerus were simulated using the numerical analysis and were loaded on each insertion point. By these procedures, superior shift and increase of stress in a cuff tear shoulder was recreated. The new component that was designed based on these results was able to decrease the stress concentration in the cement layer, which is the dominant cause of the loosening, whereas the high stress at the hood may need reconsideration of the design. The current 3-D FE model utilizing numerical analysis for determining loading conditions will enable simulations under various muscle conditions.