INTRODUCTION

The replacement of the shoulder with an anatomical joint prosthesis is a common surgical procedure, with an acceptable survival rate. There are however still unsolved issues, such as the progressive damaging of the articular surface of the polyethylene component. This is related to the production of wear debris, and may eventually lead to the loosening or destruction of the component.

For hip and knee arthroplasty several studies have reported that the thickness of the polyethylene component is an important factor regarding its stress level and damaging, [e.g. 1-2]. For the shoulder joint, there are only two numerical studies, which predict different effect of glenoid component thickness [2-3]. The thickness of the polyethylene component used in total shoulder arthroplasty is thus still an design parameter that could be improved. A thinner implant could better conform to the anatomy of the articular surface, but may also increase the damage rate.

Therefore the goal of this study was to analyze the effect of the thickness of the polyethylene glenoid component on the polyethylene and cement stress.

METHODS

A numerical musculoskeletal model of the shoulder was used for this study [ref]. This model is composed of the scapula, the humerus, the middle deltoid (MD), the anterior deltoid (AD) and the posterior deltoid (PD). Geometry and local mechanical properties of bones were obtained from CT images of a normal cadaveric shoulder. Abduction was simulated from neutral elevation to 150 degrees of abduction, with the elbow fully extended. The arm weight was 37.5 N and 10 N were added in the hand. A scapulo-humeral rhythm of 2:1 was assumed. Abduction was controlled by muscular activation through a feedback algorithm.

Muscular activation was estimated from EMG data.

The effect of the thickness of the glenoid component was evaluated by comparing three glenoid components with different thicknesses: 2 mm, 4 mm (reference) and 6 mm. We performed this study with the Aequalis anatomical total shoulder arthroplasty (Tornier). The referenced glenoid component modified using CAD software (www.solidworks.com) to design the other 2 components with thickness of 2 and 6 mm. The 3 implants were positioned in the glenoid bone in the same way. The reaming of the glenoid bone and positioning of the implants within the scapula were done with SolidWorks, according to manufacturer recommendations and assessed by a senior shoulder surgeon.

During the simulated abduction movement, we measured the muscle moment arms, muscle forces, glenohumeral reaction force, contact pressure on the articular surface, von Mises stress within the polyethylene, and maximum principal stress within the cement mantle. Polyethylene and cement stress were evaluated every 30° of abduction. All numerical analyses were performed with Abaqus version 6.8 (www.simulia.com).

RESULTS

The moment arms of the 6 scapulohumeral muscles were only lightly altered by the change of polyethylene thickness. In overall, muscle moment arms decreased by less than 1 mm as thickness increased.

This decrease of moment arms induced an increase of muscle forces (not presented here) and thus an increase of the joint reaction force. Join reaction force max maximal around 90° of abduction. It reached 955 N, 971 N and 903 N for 2 mm, 4 mm and 6 mm of polyethylene thickness.

The translation of the humerus during abduction was an up and down movement, relative to the glenoid. For the 4 mm reference thickness, the center of the humeral head migrated superiorly by about 3 mm during the first 30° of abduction, and was 1.4 mm above the perfect centering of the humeral head in the glenoid fossa. From 30 to 150° it went down slowly. The same behavior was observed with the 2 and 6 mm glenoids.

Maximal upward migration was respectively 1.5 mm and 1.3 mm for the 2 mm and 6 mm glenoid.

The contact pattern on the glenoid component also followed an up and down movement during abduction (Fig. 1). The contact pressure was maximal at 90° of abduction. It was about 150% higher with the 2 and 6 mm compared to the reference 4 mm thickness. Von Mises stress in the polyethylene was also about 150% higher with the 2 mm (28 MPa) and 6 mm (26 MPa) compared to the reference 4 mm (21 MPa) thickness (Fig. 1).

In the cement mantle, the maximum principal stress was maximal at 60° of abduction. It was about 160% higher with the 2 mm (15 MPa) glenoid, but 60% lower with the 6 mm (6 MPa) glenoid, compared to the 4 mm (9 MPa) reference glenoid.

DISCUSSION

The optimal thickness of the polyethylene glenoid component in anatomical total shoulder arthroplasty is still an open question. Using a numerical musculoskeletal model of the shoulder, we showed that polyethylene and cement stress increased largely when the thickness was reduced by 2 mm from its actual value of 4 mm. On the other side, a thickness increase of 2 mm reduced the cement stress, but induced a polyethylene stress increase.

The observed effect of a polyethylene thinning was expected and has already reported in the literature [e.g. 3]. The polyethylene stress increase observed with a thicker polyethylene component was localized at the articular surface, and was probably caused by a higher general rigidity of the component, directly related to it thicker geometry. The stress increase was also caused by the higher reaction force, related to the lower muscle moment arms. It is important to note that the thickness increase also decreased the polyethylene stress on the backside of the glenoid component (Fig. 1), inducing lower stress within the underlying cement mantle. The stress value reported here were obtain for a relatively high level of load, which is however representative of activities of daily living. The maximal stress level in the polyethylene and cement were close to the reported fatigue limits.

To conclude, this study confirms that the thickness of the polyethylene component is an important parameter of total shoulder prostheses. Finally, we recommend avoiding polyethylene component thinner than 4 mm.

ACKNOWLEDGEMENTS

This study was supported by Tornier Inc., Edina, MN.

REFERENCES

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