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Evaluation of Primary Stability of Reverse Shoulder Arthroplasty Based on Finite Element Analysis

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ABSTRACT

As the number of reverse shoulder arthroplasty (RSA) procedures increases, so does the incidence of revision surgery. Baseplate-related complications account for the highest proportion of these revisions, and it has been reported that improving baseplate fixation reduces the likelihood of failure. The present study aims to evaluate the initial stability of the baseplate to the glenoid after RSA. A finite element analysis (FEA) was performed using LS-DYNA models of the scapula and the SMR shoulder system, with a load of 30 N applied in both abduction and flexion, using the baseplate implantation surface as the reference. Micromotion was defined as the difference in displacement between the baseplate and the scapular fossa. The results demonstrated that micromotion between the glenoid and the baseplate diminished with increasing elevation in both abduction and flexion. It is hypothesised that in the SMR shoulder system, the screws are pressed into the glenoid during abduction, thereby contributing to enhanced initial stability.

1. INTRODUCTION

A large analysis of an international database reported significantly lower complication and revision rates for reverse shoulder arthroplasty (RSA) compared to total shoulder arthroplasty (TSA) [1]. In RSA, the most common cause of revision is instability, with baseplate failure accounting for 40% of these cases [1, 2]. Therefore, glenoid and baseplate fixation is a topic of discussion. Micromotion is a key indicator in assessing fixation stability [3]. In order to promote bone ingrowth at the glenoid interface, it is considered ideal to limit micromotion to a range between 50 µm and 150 µm [3-5]. The present study proposes to use this indicator to evaluate the performance of RSA from the perspective of osseointegration and to assess its initial fixation stability.

RSA increases deltoid tension because the centre of the joint is more medial during elevation than TSA [6]. It has been demonstrated that RSA enhances range of motion and stability by mobilising additional deltoid muscle fibres [7]. Consequently, the present study concentrated on abduction and flexion, which represent the fundamental movements of elevation, and calculated micromotion at four angles, including the zero position. While numerous reports have examined RSA fixation with regard to tension and micromotion, the majority of these have focused on retroversion, with only a limited number addressing fixation during abduction and flexion [8, 9]. The present study aims to evaluate the initial fixation stability of RSA during abduction and flexion by calculating micromotion at the glenoid/baseplate interface.

2. MATERIALS AND METHODS

The three-dimensional geometry of the scapula and the SMR shoulder system (Lima, Italy) were obtained from DICOM data. The SMR shoulder system consists of a 36 mm glenosphere, a baseplate with a central pin and superior and inferior screws. The models consisted of a total of 243,996 elements, which were refined to improve accuracy. The material properties of the analysis model were defined as follows: the glenosphere, baseplate and central pin were made of CoCrMo; the superior and inferior screws were made of Ti6Al4V; and the scapula was assumed to be cancellous bone (**Table 1**) [10-12].

The loading condition was 30 N applied to the upper arm. The weight of an elderly Asian male was assumed to be 50 kg, and the load applied to the glenosphere was calculated to be 6% of the weight of the upper arm. The load direction was set to 0˚, 45˚, 90˚, and 135˚ of abduction based on the base plate mounting surface to simulate lifting (**Figure 1**). To avoid scapular notching, the glenosphere was positioned 4 mm inferior to the glenoid center. Finite element analysis (FEA) was performed using LS-DYNA ver. R11.1 (LSTC, CA, USA) using a static implicit method.

To validate the model, the simulation results were compared with those reported in the literature [8, 9]. The loading conditions described in the literature involved a 100 N load applied perpendicular to the contact surface between the bone and the baseplate. To ensure an accurate comparison, the reported conditions were replicated. The validated model was then used to calculate micromotion. Micromotion was defined as the relative displacement obtained by subtracting the displacement of the scapula from that of the baseplate (**Figure 2**).

Table 1. Material properties.

	CoCrMo	Ti6Al4V	Scapula
Density [kg/m^3]	8300	4400	1800
Elastic modulus [MPa]	215000	100000	17000
Poisson's ratio [-]	0.30	0.34	0.30

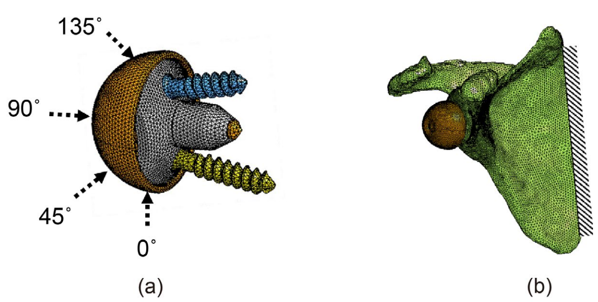

Figure 1. Analysis conditions. (a) Load conditions. 30 N was applied in the direction of the arrow. (b) Boundary condition. The shaded area was fixed.

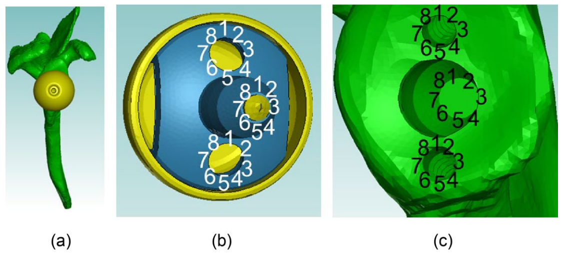

Figure 2. Model and displacement measurement locations. (a) Model of the scapula and glenosphere viewed from the x-axis. (b) Displacement measurement locations on the baseplate. (c) Displacement measurement locations on the glenoid.

3. RESULTS

The micromotion results calculated for model validation were consistent with those reported in the literature (Table 2). Focusing on the x-axis in the direction the screw exits, Figure 3(a) shows that the displacement is greatest in the direction the base plate pushes in at abduction 45˚. In the case of flexion, the displacement along the y-axis is shown in Figure 3(b), focusing on the anterior-posterior direction, which indicates that the top of the base plate shifts posteriorly due to flexion.

Table 2. Model validation using micromotion.

	Micromotion [μm]
Our results	3.73
Results from literature [Friedman 2021]	2.53
Results from literature [Farron 2006]	5.75

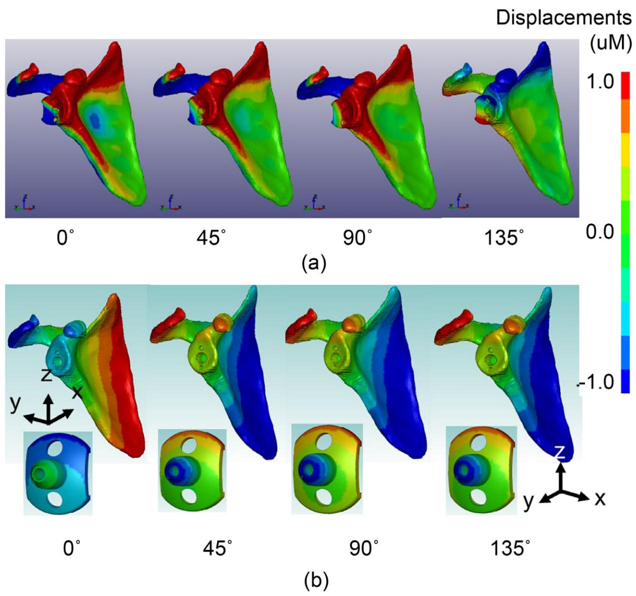

Figure 3. Distribution of displacements. (a) Abduction along the x-axis. Positive values indicate displacement of the baseplate into the glenoid, while negative values indicate displacement away from the glenoid. (b) Flexion along the y-axis. Positive values indicate displacement toward the posterior, while negative values indicate displacement toward the anterior.

In abduction, the absolute value of the micromotion of the glenoid and baseplate was greatest in the zero position among the four conditions (**Figure 4(a)**). As the abduction angle increased from 0˚ to 90˚, the superior screw shifted in a direction that pressed it into the glenoid, while the inferior screw exhibited greater micromotion in the x-, y-, and z-axes at the zero position.

In flexion, the maximum micromotion along the y-axis was 7.5 μm (**Figure 4(b)**). The superior screw exhibited a slight posterior shift at 0˚, an anterior shift at 45˚, and a maximum displacement at 90˚, followed by a decrease at 135˚. Concurrently, both the superior and inferior screws demonstrated an anterior movement, while the central peg exhibited a posterior shift. The maximum micromotion observed was 6.5 μm along the y-axis at flexion 135˚ at the central peg, and 3.9 μm along the z-axis at the superior screw at flexion 135˚.

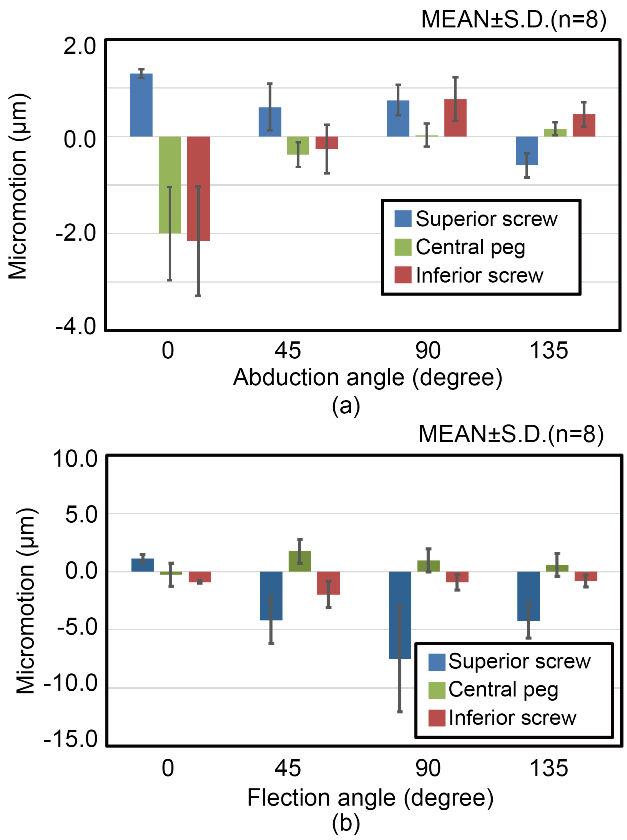

Figure 4. Micromotion. (a) Abduction along the x-axis. Positive values indicate displacement of the baseplate into the glenoid, while negative values indicate displacement away from the glenoid. (b) Flexion along the y-axis. The upper four figures show the scapula. The lower four figures show the baseplate viewed from the glenoid. Positive values indicate displacement toward the posterior, while negative values indicate displacement toward the anterior.

4. DISCUSSION

The issue of loosening between the glenoid and the baseplate remains a significant concern, as excessive micromotion has the potential to compromise initial stability [8]. Consequently, there is considerable interest in micromotion, and a substantial number of studies have been reported in both clinical and biomechanical research [4, 9, 13, 14]. It is essential to continue to organise and discuss the relationship between different implants and their clinical outcomes.

In an in vitro study of SMR, the maximum micromotion of the baseplate was reported to be 26.8 μm, which is comparable to our value [14]. It has been reported that if the micromotion between the glenoid and the base plate does not exceed 150 μm, bone growth is promoted [3].

As the micromotion values observed in this study were all below this threshold, it can be concluded that SMR promotes bone growth and leads to primary stability. During arm elevation in abduction, superior screw shifting in a direction that presses it into the glenoid is considered beneficial for fixation. In the case of flexion, 90˚ was considered a more critical condition compared to 135˚. The micromotion of the central peg remained below 2 μm in both abduction and flexion, indicating sufficient stability and a reduced risk of loosening.

The limitations of this study include the assumption that the scapula is a homogeneous material and the exclusion of muscles and ligaments in the analysis. While these factors may affect the micromotion values, they are unlikely to alter the main conclusions. We aimed for a straightforward conclusion by varying only the loading conditions and minimizing additional parameter combinations. In subsequent studies, we intend to extend our analysis by incorporating parameters such as glenoid inclination.

5. CONCLUSION

It was revealed that the micromotion between the glenoid and the baseplate decreased with arm elevation in both abduction and flexion. Given that the screws in the SMR shoulder system are pressed into the glenoid during abduction, it can be inferred that this mechanism contributes to the initial stability of the implant.

CONFLICTS OF INTEREST

The authors declare no conflicts of interest regarding the publication of this paper.

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