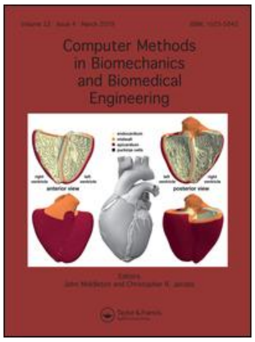

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Overcorrected glenoid implants to prevent recurrent glenohumeral subluxation after total shoulder arthroplasty: a patient-specific finite element analysis

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KEYWORDS Shoulder; arthroplasty; glenoid implant; glenohumeral subluxation; finite element

1. Introduction

Glenohumeral osteoarthritis is common in the elderly. It causes pain and reduces mobility. In advanced stages, total shoulder arthroplasty (TSA) is recommended. Even though TSA is an established procedure, its failure rate and revision surgeries are relatively high. One of the main causes of failure is glenoid implant loosening, often associated with off-centre loading. The latter may be reinforced by the presence of glenohumeral joint subluxation. Glenohumeral subluxation is defined as the relative position of the humeral head with respect to the glenoid cavity. In patients planned for anatomic TSA (aTSA) and presenting a risk of recurrent postoperative glenohumeral subluxation, asymmetrical overcorrected glenoid implants have been suggested as an alternative to classical implants. The potential advantages of these asymmetrical implants have however never been assessed clinically. The aim of the present work was to evaluate the potential biomechanical advantages of the overcorrected implant compared to a standard one, with patient-specific numerical methods.

2. Methods

2.1. Patient-specific modelling

We considered an 80-year old female patient who underwent aTSA at Lausanne University Hospital. This patient received an Aequalis PerFORM glenoid implant (Tornier, Bloomington, MN, USA) on the left shoulder, and an Aequalis PerFORM+ posterior keeled augmented glenoid implant on the right shoulder. For both shoulders, a specific finite element model was created. Scapulae models were created from preoperative CT data using Amira 6.2.0 (FEI Visualization Sciences Group, Burlington, MA, USA). Trabecular and cortical bone were segmented separately. The geometry was imported in a CAD software Solidworks (2015, Dassault Systèmes, Vélizy-Villacoublay, France). The implants were virtually inserted following the surgeon's instructions and postoperative CT data. A cement layer (0.5 mm thick) was added between the implant and the bone. The CAD models of the implants were provided by the company. Homogeneous and isotropic material properties were assigned to trabecular bone, cortical bone, cement, and polyethylene, while the humeral component was considered rigid. Average elastic properties of bone were estimated from CT data.

2.2. Overcorrected implant design

Based on the surgeon's recommendations, a posterior overcorrected implant of 10° was tested for both shoulders, and compared to the non-overcorrected one. This overcorrection design modification was performed on the articular side, without changing the bone side of the implant. In total, 4 cases were tested: a standard implant non-overcorrected (STD-nOC) and its overcorrected version (STD-OC) for the left shoulder, and an augmented non-overcorrected (PAG-nOC) implant with its overcorrected version (PAG-OC) for the right shoulder. The glenoid version after TSA was 5.5° with the STD, 4° with STD-OC, 4.8° with PAG, and 3.3° with PAG-OC. These angles were measured in 3D in the scapular coordinate system (Terrier et al. 2014).

2.3. Loading

To test the potential of the overcorrected implant to prevent subluxation, we replicated the ASTM F2028 (ASTM-F2028-14). The scapula was fixed at the medial side, and a posterior subluxation force was applied on the humeral implant. An axial compressive force of 750 N was added to a posterior transverse force of 241 N for the right shoulder and 231 N for the left shoulder.

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2.4. Finite element analysis

For the 4 tested cases, we evaluated the subluxation (offset between scapular axis and humeral head centre), maximum principal stress within polyethylene, and cement volume with minimum principal stress above a fatigue limit of 7 MPa (Lewis 1997). This volume was normalized to 649 mm^3. Finite element analyses were performed with Abaqus (Simulia, Dassault Systems, France).

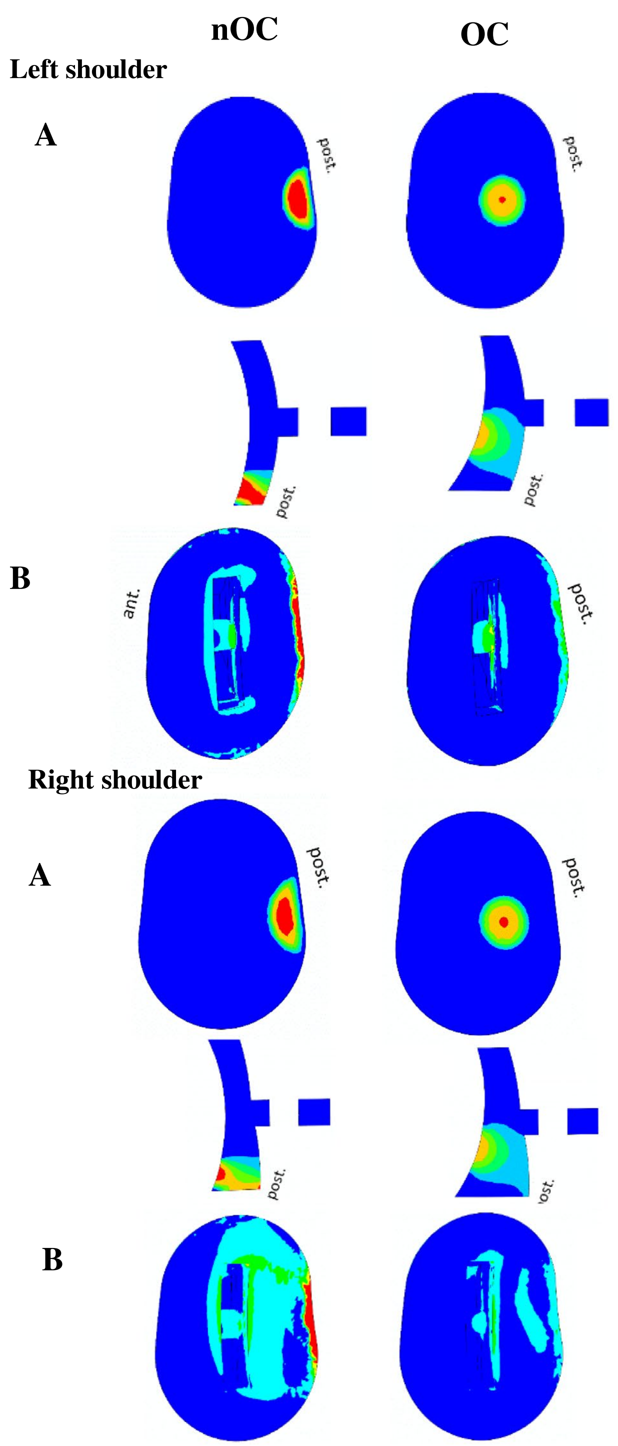

Figure 1. A: Maximum principal stress on glenoid implant for left shoulder: STD-nOC (l.) and STD-OC (r.) and right shoulder: PAG-nOC (l.) and PAG-OC (r.). Maximum values (red) range between 25-30 MPa. B: Minimum principle cement volume stresses. Maximum values (red) range between 8–10 MPa (red).

3. Results and discussion

OC design reduced glenohumeral subluxation on both shoulders. The humeral head centre offset changed from 3.1 mm posteriorly to 3.1 mm anteriorly for the left shoulder. Normalized over a humeral head radius of 22 mm (Terrier et al. 2015), subluxation amplitude thus changed from 14% posteriorly to 14% anteriorly. For the right shoulder, the offset changed from 3.4 mm (i.e. 15%) posteriorly to 2.0 mm (i.e. 9%) anteriorly for the right shoulder. This anterior translation of the humeral head resulted in a more centred gleno-humeral contact pattern, and lower polyethylene and cement stress (Figure 1). Peak contact pressure decreased from 32 to 24 MPa for the left shoulder and from 29 to 24 MPa for the right shoulder when using OC. Maximum principal stress decreased from 30 to 20 MPa. With OC, cement volume above fatigue limit was reduced from 0.5% (3.25 mm^3) to 0.01% (0.08 mm^3) for the left shoulder, and from 0.22% (1.41 mm^3) to 0.06% (0.42 mm^3) for the right shoulder (Figure 1).

4. Conclusions

The present patient-specific numerical study confirmed the assumed potential advantages of overcorrected glenoid implant designs to reduce the risk of recurrent subluxation after aTSA. The analysis showed that overcorrected designs prevent subluxation and reduce stress within implant and cement. This preliminary study should be validated with experimental measurements and extended to more patients. Eventually, the specific indications for the overcorrected implant placement should be evaluated.

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