Introduction: Reversed shoulder prostheses are being increasingly used as a satisfying solution for glenohumeral arthropathy associated with partial or severe rotator cuff deficiency [1]. Despite reported complications, this non-anatomical implant provides indeed a significant improvement of pain relief and mobility.

The biomechanics of this implant is based on two main features: it is semi-constrained and it mediates its rotation center. The constraint restores the lost stability, which was provided by the rotator cuff muscles, while the center medialization increases the deltoid moment arm and thus the muscular strength, which was also diminished by the rotator cuff deficiency. However, although the general mechanism of this non-anatomical implant is known, the biomechanical gain is not clearly quantified.

The aim of this study was therefore to compare a reversed shoulder prosthesis to an anatomic one, regarding the glenohumeral contact force and electromyography data [2]. At each abduction angle, all muscle forces and muscle forces were also compared.

Materials and Methods: Analysis was conducted with a 3D finite element model of the shoulder. This model was build from CT scans of a normal cadaver shoulder. Six muscles were included: middle, anterior and posterior deltoid, supraspinatus, subscapularis, and infraspinatus combined with teres minor. Muscles were characterized by a soft neo-Hookean law reinforced with stiff fibers along the principal direction of tension, allowing for large bending deformation, but high resistance in tension. Bones and metal components were rigid, while polyethylene was a deformable linear elastic material. The natural stability of the joint was achieved by the wrapping of the muscles around the humeral head and the glenohumeral contact surfaces, allowing for natural translation of the humerus. Abduction was simulated in the scapular plane by active muscle forces, controlled through a feedback algorithm. This algorithm synchronized the muscles such that their force amplitudes were maintained proportional to fixed ratios derived from physiological cross-sectional area and electromyography data [2]. At each abduction angle, all muscle forces satisfied this ratio condition, as well as the equilibrium equations together with the arm weight, the glenohumeral contact forces and bone-muscles contact forces. The rotation of the scapula was accounted for by using a scapulohumeral rhythm of 2:1. The arm weight was set to 37.5 N (5% of bodyweight), applied at the gravity center of the extended arm (320 mm from the humeral head center). The reversed and anatomic Acqualis prostheses, provided by the manufacturer (Tornier S.A.S, Montbonnot, France), were numerically inserted into the shoulder model, according to the recommended technique. With the reversed implant, rotator cuff muscles were deactivated. The numerical analysis was performed with the implicit solver of Abaqus 6.5. For both prostheses, the following quantities were calculated by the solver during the entire range of abduction: amplitude, direction and application point of the glenohumeral contact force, maximum and mean (contact force/contact area) contact pressure, amplitude of the muscle forces. Besides, the muscle moment arms were also calculated with the tendon excursion method.

Results: With the anatomic prosthesis, classical results were retrieved: joint force was maximal at approximately 90 degrees of abduction, reaching 86% of the body weight. For the reversed implant, the contact force was also maximal around 90 degrees of abduction, but the amplitude of the force was 50% lower. The location (contact point) and direction of this force were also very different for each design (fig. 1). Again, known results were obtained with the anatomic implant. With the reversed implant, the location of the contact point on the glenoid side (glenosphere) moved continuously from the inferior part towards its center during abduction. Conversely, on the humeral side (polyethylene cup), the contact point remained located in the same inferior position during the entire range of abduction (fig. 1). The reversed prosthesis required approximately 50% less muscular force than the anatomic one, but the overall deltoid force was only reduced by 20%. At 90 degrees of abduction, the maximum (resp. average) contact pressure was 1.2 PMa (resp. 0.5 PMa) with the reverse prosthesis, vs. 19.0 MPa (res. 7.9 MPa) with the anatomic one. The moment arm of each deltoid part was up to 20 mm higher with the reversed design, particularly at the beginning of abduction.

Discussion: The reverse prosthesis medializes the rotation center, which increases the deltoid moment arms, and thus reduces the overall muscle force required for elevation. In this numerical study, this mechanism was reproduced. The contact force and contact pressure were quantified and compared to an anatomic prosthesis. The model confirmed that abduction with a reversed prosthesis can be performed without rotator cuff muscles, and even with a weaker deltoid, but produced very different contact forces. Because of a lower contact force and a higher contact area, the glenohumeral contact pressure dropped considerably. This should be associated to a much lower lever of wear, assuming that impingements are avoided.


Acknowledgements: This study was partly supported by Tornier SAS, Montbonnot, France.