Advantages of an anatomical humeral head reconstruction during shoulder arthroplasty. A finite element analysis.

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Introduction
The latest evolution in shoulder arthroplasty is towards the restoration of the original anatomy of the proximal humerus. New prosthetic designs allow for the adaptation of the implant to the anatomy of the patient during the surgical procedure (Boileau et al.). Restoration of the original bone shape should reestablish original kinematics, muscular forces, intrasosseous stresses and the joint’s centre of rotation (Pearl et al.). As far as we know, no biomechanical study has confirmed these hypotheses. The objective of this work is to assess the influence of an anatomical humeral head reconstruction on shoulder biomechanics. A numerical model of the glenohumeral joint has been developed and used to compare the biomechanical behavior of a first generation monobloc shoulder hemiprosthesis (Neer II) to that of an anatomical custom-made implant.

Methods
A 3D finite element model of the shoulder was developed from the shoulder of an intact human cadaver without any evidence of pathology. Data were obtained from CT scan of a thorough dissection. The model takes into account the accurate bone geometry and the bone density distribution of the entire scapula and the upper half of the humerus, the three major rotator cuff muscles and the articular cartilage. It includes non-homogenous bone constitutive laws and large slip contact at the articular surface. Cartilage was assumed to be hyperelastic and incompressible. Muscles were 3D reconstructed from their humeral and scapular insertions. Sliding contacts were assumed between muscles and bones and the nonlinear passive behaviour of muscles was taken into account.

A first generation (Neer II) monobloc humeral hemiprosthesis was reconstructed. An anatomical custom-made humeral head was also developed. To have two comparable situations the custom-made head was placed on the same stem as the Neer II implant. The design of the anatomical humeral head is an ellipsoid for a best fit with the original humeral head. The two hemiprostheses were numerically implanted into the same humerus with an identical plane of osteotomy (Figure 1).

Figure 1: Finite element mesh of the intact shoulder (a), after the Neer II hemiarthroplasty (b), and the anatomical custom-made hemiarthroplasty (c).
We simulated movements of internal (0° to 60°) and external (0° to 40°) rotations. The movements were achieved by a gradual displacement of scapular muscle extremity (infraspinatus for external rotation, subscapularis for internal rotation) with all other muscles inserted into bones at both ends. The scapula was floating, maintained by flexible elements replacing stabilising muscles. The distal humerus section was stabilised by four vertical flexible elements to preclude any significant movement of abduction. We calculated the muscular forces developed in the rotator cuff, the glenohumeral contact pressures and the intraosseous bone stresses. We compared the results obtained with the intact shoulder to those of both hemiprotheses.

Results

**Contact pressure:** The glenohumeral contact pressures were similar in the intact shoulder and with the anatomical custom-made implant, but were higher with the monobloc Neer II implant (up to 80% for the external and up to 140% for the internal rotation). Furthermore the contact zone remained centered on the glenoid fossa for the intact shoulder and with the anatomical custom-made implant. We observed a slight superior and posterior migration of the contact with the monobloc Neer II shoulder.

![Figure 3: Contact pressures on the glenoid fossa at 60° of internal rotation for the intact (a), the monobloc Neer II (b) and the anatomical custom-made (c) shoulders.](image)

**Stress:** The peak values of Von Mises stresses within the scapula were similar in the intact shoulder and with the anatomical custom-made implant, but higher with the Neer II implant. However, the distribution of the Von Mises stresses were very dependent on the location of the glenohumeral contact zone. For instance, at the level of glenohumeral contact for the monobloc Neer II implant (Figure 3), the stresses in the glenoid were about 500% higher with the Neer II shoulder than for the two other cases.

![Figure 3: Von Mises stresses in an axial plan, at 40° of external rotation.](image)

**Force.** During external rotation, the forces developed in the active muscle (infraspinatus) were similar for the three cases. At 60° internal rotation, the forces developed in the active muscle (subscapularis) were about 33% less with the monobloc Neer II shoulder, than with to the two other cases (Figure 4).
**Discussion**

This study shows that with an anatomical reconstruction of the humeral head, induced bone stresses, muscular forces and glenohumeral contact pressures, are similar to those of the original intact humerus. Keeping the same bone geometry, the same muscle properties, and with the same boundary conditions, this indicates that restoration of humeral head leads to more physiological biomechanical behavior. The shape of the humeral head should also influence the forces and stresses transmitted to a prosthetic glenoid after total shoulder replacement. While this could play an important role in the process of glenoid wear and loosening, further studies are necessary to confirm this hypothesis.

**References**

Pearl et al., *JBJS [Am]*, 81, 660:71, 1999

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