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ORIGINAL ARTICLE

Biomechanical comparison of glenoid implants with adaptable and fixed backside curvatures in anatomic total shoulder arthroplasty

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Background: We evaluated the biomechanical effects and potential advantages of glenoid implants with adaptable backside curvature radii and compared them with standard implants having fixed backside curvatures in anatomic total shoulder arthroplasty (aTSA) for primary glenohumeral osteoarthritis with uniconcave glenoids.

Methods: A glenoid implant with adaptable backside curvatures (Aequalis PerFORM, Tornier SAS, Montbonnot, France) was compared with its previous model having a fixed curvature radius. Virtual aTSAs were performed in 24 patients from preoperative shoulder computed tomography data sets, using both implants in each patient. For all 48 simulated aTSAs, we first measured the glenoid bone reaming depth, subchondral bone quality after reaming, and implant backside surface and then the predicted cement stress, bone–cement interfacial stress, and bone strain at 60° of arm abduction. These biomechanical quantities were tested for differences between adaptable and fixed implants and for correlations between preoperative measurements and postoperative predictions.

Results: Adaptable glenoid implants induced a significant decrease in cement stress ($P = .008$), bone–cement interfacial stress ($P = .045$), and bone strain ($P = .039$), particularly for glenoids with curvature radii larger than 40 mm. However, these biomechanical effects were not significantly correlated with an increase in subchondral glenoid bone quality.

Conclusions: Our study confirms the presumed biomechanical advantages of adaptable glenoid implants, even though the effects were not directly due to the adaptation of the backside curvature radius. Benefits were more pronounced for glenoids with large curvature radii. Our initial biomechanical findings should now be corroborated with large-scale clinical studies.

Level of evidence: Basic Science Study; Biomechanics

Keywords: Anatomic total shoulder arthroplasty; aseptic loosening; bone mineral density; bone quality; computed tomography; glenoid implant

Protocol for this study was approved by the institutional ethics committee (La Commission cantonale d'éthique de la recherche sur l'être humain) (protocol 136/15), with waiver of informed consent.

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Anatomic total shoulder arthroplasty (aTSA) is an effective treatment for primary glenohumeral osteoarthritis (OA), but aseptic loosening of the glenoid component remains a major concern, the causes of which can be multiple.[14] The latest developments in shoulder arthroplasty have focused on increasing the glenoid bone support. It is indeed assumed that maximizing glenoid bone support is an essential step to promote the long-term survival of the glenoid component.[6,19,26,27,29]

To maximize the bone support of the glenoid implant, minimal glenoid bone reaming should be performed to preserve the subchondral bone quality, yet the implant backside should fit the reamed glenoid. These 2 constraints may, however, be difficult to achieve when using glenoid implants with fixed backside curvature radii due to the great variability of curvature radii of glenoid cavities in both normal and OA glenoids.[7,12,13,20,23]

However, most currently available glenoid implants have flat or fixed backside curvature radii because they were initially developed for "regular-shaped" (nonbiconcave, no substantial posterior wear with glenoid retroversion) OA glenoids and based on average curvature radii of glenoid cavities from non-OA shoulders.[14,16,27]

Different types of implant backsides have recently been developed to better fit the patient-specific glenoid bone morphology. For regularly shaped glenoid cavities, the use of reamers with variable curvature radii and the corresponding glenoid components was indeed suggested.[25] Walch et al[25] reported that future clinical and biomechanical studies would help determine whether implants with adaptable backside curvature radii can help prevent glenoid implant failure related to over-reaming or under-reaming.[25] These 2 issues have not been thoroughly investigated so far, yet encouraging initial midterm results of such implants with adaptable backside curvature radii have recently been reported.[3]

The objective of our study was therefore to evaluate the biomechanical effects and potential advantages of glenoid implants with adaptable backside curvature radii and compare them with standard implants with fixed backside curvatures. For this comparison, we performed 2 paired virtual arthroplasties on patients planned for aTSA, one using a standard glenoid implant and the other with an adaptable implant. We then compared several biomechanical quantities between these 2 implants and calculated correlations between them.

Materials and methods

We compared 2 different models of the keeled Aequalis prosthesis (Tornier SAS, Montbonnot, France): the standard glenoid implant with a fixed curvature radius (36.5 mm), and the Aequalis PerFORM glenoid implant with adaptable curvature radii of 30, 35, 40, 50, and 60 mm. The standard implants come in three sizes: small (S), medium (M), and large (L), and there was an additional extra-large (XL) size for the adaptable implant. We virtually inserted these 2 implants in patients and searched for differences and correlations between various biomechanical quantities.

Patients

We defined 3 patient groups according to the curvature radius of the preoperative glenoid cavity: Rs, R–, and R+. The radius was close to the standard implant value (35.5 mm) in the Rs group, was smaller (<30 mm) in the R– group, and larger (>40 mm) in the R+ group. From our institutional database we selected 8 patients per group who were planned for and underwent aTSA between 2005 and 2015.

Inclusion criteria were primary glenohumeral OA treated with aTSA and availability of a preoperative standardized nonarthrographic shoulder computed tomography (CT) scan. We excluded shoulders with biconcave (Walch B2) glenoids, preoperative glenoid versions >20°, and scapulohumeral subluxations >70%. Age, sex, and body mass index (BMI) were not considered for patient selection and group definition.

CT protocol

Nonarthrographic shoulder CT scans were performed using 8- and 64-detector row CT systems (LightSpeed Ultra, LightSpeed VCT, and Discovery CT750 HD; GE Healthcare, Milwaukee, WI, USA) with the following standardized acquisition parameters: tube potential, 120 kVp; tube current, 180 to 340 mA; and gantry revolution time, 0.5 to 0.8 seconds. Image reconstruction parameters were field of view, 16×16 to 26×26 cm (yielding in-plane pixel sizes of 0.31×0.31 to 0.51×0.51 mm); section thickness, 0.6 to 2.5 mm; and section overlap, 0.3 to 2.0 mm.

Preoperative CT measurements

Glenoid curvature radius and version as well as static scapulohumeral subluxation were measured in 3-dimensions (3D) from preoperative CT data sets.[22,23] Subluxation was reported as an offset percentage of the humeral head radius. Degeneration ratios of the 4 rotator cuff muscles were semiautomatedly quantified in 2D on a standardized sagittal-oblique CT section with the use of user-defined MATLAB scripts (The MathWorks, Natick, MA, USA).[21] For each muscle, the degeneration ratio corresponded to the residual muscle cross-sectional area (minus fatty infiltration and secondary bone formation areas) divided by the presumed surface of the normal muscle.

Shoulder arthroplasty simulations

We generated 3D geometric models for all patients using their preoperative CT data sets. Bones were first segmented using the Amira visualization software (FEI Visualization Sciences Group, Burlington, MA, USA), and bone surfaces subsequently created with Geomagic (3D Systems, Research Triangle Park, NC, USA). We then virtually inserted the 2 different glenoid implants in each patient according to the manufacturer's recommendations. The glenoid component was aligned within 10° of the mediolateral scapular axis, while attempting to maximize glenoid bone support (minimize reaming) for each case and implant type. An ideal cement layer with a uniform thickness of 0.5 mm was reproduced in all models.[17] The humeral component was also virtually implanted by considering the manufacturer's radius-matching tables. All virtual shoulder arthroplasties were performed using SolidWorks (Dassault Systèmes, Vélizy-Villacoublay, France) and both were verified and corrected by an experienced shoulder surgeon (A.F.).