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Perforation tolerance of glenoid implants to abnormal glenoid retroversion, anteversion, and medialization

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Background: Loosening of the glenoid implant is a common complication of total shoulder arthroplasty. To prevent this, we need to ensure the glenoid vault is not perforated during insertion of the glenoid implant to allow for cement containment and maximum pressurization. Factors affecting perforation potential include glenoid implant design and alignment. This study looks at the perforation tolerance of 15 commercially available glenoid implants to increased retroversion, increased anteversion, and medialization.

Materials and methods: Accurate 3-dimensional models of the 15 glenoid implants were created from exact dimensions obtained from the manufacturers and virtually implanted into 3-dimensional reconstructed models of 40 nonarthritic scapulae. Perforation tolerances of each implant to increased retroversion, increased anteversion, and medialization were determined through computer simulation to represent asymmetrical arthritic posterior wear, anterior wear, and eccentric corrective reaming, respectively.

Results: In all 15 glenoid implants, the overall mean increased retroversion tolerated before perforation was 19°, increased anteversion was 16°, and abnormal version fully corrected by eccentric reaming was 17°. Each glenoid implant was evaluated individually to allow for direct comparison and, finally, size-matched and downsized glenoid implants in relation to the size of the humeral head.

Conclusion: The results from this study help surgeons, when faced with a severely arthritic glenoid, to choose the appropriate glenoid implant to minimize perforation potential, and provide guidance on how much abnormal version and how much corrective reaming can be tolerated before perforation occurs and fixation is compromised. These results can also help with future implant designs.

Level of evidence: Basic Science, Computer Modelling.

Keywords: Shoulder arthritis; glenohumeral arthritis; glenoid retroversion; glenoid anteversion; glenoid medialization; total shoulder replacement; perforation; computer simulation

A recent review of 40 studies comprising 3584 patients[13] revealed that a common complication of shoulder arthroplasty is loosening of the glenoid implant, ultimately leading to the demise of the total shoulder joint replacement; loosening, defined as radiographic evidence of migration, tilt, or shift of the implant; or a complete radiolucent line of >1.5 mm thick at the cement–bone interface. A secure glenoid implant is crucial to a successful shoulder arthroplasty. One important factor to avoid loosening of the glenoid implant is its containment within the glenoid vault, which allows for pressurization of the cement when the prosthesis is implanted. This ensures maximal interdigitation of the cement within the cancellous bone to enhance the implant–cement–bone interface.[9] For this to occur, it is

Ethical committee approval was not required for this study.

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critical that the glenoid wall is not perforated during the drilling process to accommodate the pegs or keel of the glenoid component.

Factors that contribute to perforation potential include the available glenoid bone stock and its shape, which is normally quite consistent[3] but changes with asymmetrical arthritic wear; usually resulting in abnormal increased retroversion.[14] We cannot control these factors, but we can choose the glenoid implant inserted, from which there are many to choose, and the position in which the implant is placed in, whether in an increased retroverted position or in a medialized position after intraoperative eccentric corrective reaming resulting in decreased bone stock. The surgeon's operative skill and understanding of the patient's glenoid bone deformity through preoperative planning and knowledge of specific implant thresholds is important in minimizing perforation potential.

The objectives of this study were to look at 15 glenoid implant designs from 4 major manufacturers to determine the perforation potential of each implant, specifically looking at the amount of abnormal version (increased retroversion and increased anteversion) and medialization that could be tolerated before perforation of the glenoid wall. With our data, we hope to provide a guide for surgeons of perforation potential when selecting the glenoid prosthesis for an arthritic glenoid. This is solely a volumetric study looking at glenoid wall perforation potential in relation to the dimensions and orientation of the different peg or keel designs.

Materials and methods

Three-dimensional computed tomography reconstructed scapula models

We obtained 40 shoulder computed tomography (CT) scans performed through North Shore Hospital for acute fracture assessment. These were carefully identified as normal glenohumeral joints without any evidence of arthritis (cyst, osteophytes, subchondral sclerosis or decreased joint space) on x-ray images or CT scans. The pathologies in this group included proximal humeral, clavicular, and scapular body fractures. The MIMICS program (Materialise, Leuven, Belgium) was used to accurately convert each of the 40 shoulder CT series to surface 3-dimensional (3D) models, which we used for our computer simulation.

Glenoid implants

Current glenoid implants are fixed into the glenoid bone with a variety of anchor designs in different shapes and sizes. Two broad groups include the peg or keel, the former being available as a single peg, a 3-peg in a vertical line, and a 4-peg in an inverse T design. To determine the perforation potential of a number of commercially available glenoid implants, the 3D mechanical computer-aided design program SolidWorks (Dassault Systèmes, Vélizy, France) was used to accurately reproduce 3D models of the glenoid implants from exact dimensions obtained from their corresponding manufacturers: DePuy (Warsaw, IN, USA), LIMA (Udine, Italy), Tornier (Amsterdam, The Netherlands), and Zimmer (Warsaw, IN, USA).

The glenoid implant consist of 2 important components, the face and the anchor (peg or keel), both of which vary in size and shape independently. It is the dimensions of the anchor that is the integral part of this study.

From the DePuy Global Advantage system, we evaluated the anchor peg with a 4-peg inverse T design in 2 sizes, despite having 6 different face sizes. Its keel design comes in 7 sizes, increasing in size relative to the size of the face. Only the smallest, middle, and largest keel sizes were used in the study, except for during the size-matched and downsized simulation.

From the LIMA SMR system, we evaluated the 2 different pegged designs, a 1-peg and a 3-peg vertical line design, both anchors in 1 size despite having 2 different face sizes each. LIMA has no keel anchors in their range but has a metal-back implant that requires 2 screws for supplementary fixation. This is an uncemented prosthesis and was excluded from this study.

From the Tornier Aequalis system, we evaluated the 4-peg inverse T design in 1 size and a keel design in 1 size despite 6 different face sizes each.

From Zimmer's Bigliani-Flatow system, we evaluated the 3-peg vertical line design in 3 sizes and the keel design in 3 sizes, its anchor increasing in size relative to the size of the implant face. Zimmer also has a trabecular metal implant that depends on bony ingrowth instead of cement fixation and was therefore excluded from this study (Fig. 1).

Virtual implantation and simulation

The 3D glenoid implant models were imported into the MIMICS program, and with surface markers, each glenoid implant was virtually implanted into the glenoid bone to simulate intraoperative insertion, and 100% contact of the glenoid implant with the glenoid articular surface was ensured (Fig. 2). Our glenoid bones were free of arthritis, so we presumed that with the above technique, the glenoid implant was placed in its most ideal position of normal version without any abnormal version or medialization.

Each of the 15 glenoid implants was implanted into the 40 scapulae. To determine the perforation tolerance of each implant, we simulated increased retroversion to represent asymmetrical posterior arthritic wear, the angle at which the anchor perforates the glenoid wall was recorded. We also simulated increased anteversion to represent asymmetrical anterior arthritic wear, and medialization at normal version to represent the amount of full corrective reaming that can be performed intraoperatively before perforation (Fig. 3).

These simulations were performed on each of the 15 glenoid implants in each of the 40 scapulae and we obtained the average value of increased retroversion, increased anteversion, and medialization at normal version that could be tolerated before perforation of the glenoid wall for each of the 15 glenoid implants. These average values allow for direct comparison between the different glenoid implant designs.

For the medialization data, our study gave us a mean distance in millimeters before glenoid wall perforation as the glenoid implant was medialized at normal version. With this value and