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A patient-specific guide for optimizing custom-made glenoid implantation in cases of severe glenoid defects: an in vitro study

Koen Eraly, MSc[a,b], Danny Stoffelen, MD, PhD[c], Jos Vander Sloten, PhD[a], Ilse Jonkers, PhD[d], Philippe Debeer, MD, PhD[e,*]

[a]*Department of Mechanical Engineering, Katholieke Universiteit Leuven, Heverlee, Belgium*
[b]*R&D Department, Mobelife, Heverlee, Belgium*
[c]*Orthopaedics, GasthuisZusters Antwerpen (GZA) St Augustinus Hospital, Wilrijk, Belgium*
[d]*Department of Kinesiology, Katholieke Universiteit Leuven, Heverlee, Belgium*
[e]*Orthopaedics, University Hospitals Leuven and Department of Development and Regeneration, Katholieke Universiteit Leuven, Pellenberg, Belgium*

Background: Glenoid component and screw malpositioning in cases of severe glenoid defects might result in complications. We examined the efficacy of a surgical method to treat severe glenoid defects, including a custom-made glenoid component and accurate screw positioning, using a patient-specific positioning guide.

Methods: Glenoid defects were created in 10 cadaveric shoulders. Computed tomography images were used to plan reversed shoulder arthroplasty and design patient-specific glenoid components. A patient-specific positioning guide was designed for 5 specimens. The remaining 5 specimens were implanted without the guide. Computed tomography images were used to determine the postoperative glenoid component and screw positions. Differences from the preoperatively planned implant and screw positions were calculated.

Results: The patient-specific positioning guide significantly reduced the angular deviations from the planned glenoid implant positioning ($P < .05$) and also significantly improved the positioning of the screws ($P < .001$). In the group without the guide, the average total intraosseous screw length was 52% of the ideal preoperatively planned length compared with 89% for the group with the guide. A strong correlation ($r = -0.85$) was found between the orientation of the implant and the postoperative total intraosseous screw length.

Conclusions: A patient-specific positioning guide significantly improves the position and fixation of a custom-made glenoid component in cases of severe glenoid defects.

Level of evidence: Basic Science Study, Surgical Technique, Cadaver Model.

Keywords: Glenoid defects; reverse shoulder arthroplasty; custom-made implant; patient-specific guides

This study was approved by the University Hospital Leuven Ethical Committee (NH019-2012-09-01).

*Reprint requests: Philippe Debeer, MD, PhD, Orthopaedics, University Hospitals Leuven & Department of Development and Regeneration, KU Leuven, Weligerveld 1, B-3212 Pellenberg, Belgium.
E-mail address: philippe.debeer@uzleuven.be (P. Debeer).

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Revisions of total shoulder arthroplasties are becoming increasingly frequent and often constitute a major surgical challenge due to considerable bone loss at the glenoid or humeral side. Glenoid bone deficiencies complicate reimplantation of an anatomic glenoid component in case of total shoulder arthroplasties or a glenosphere in case of reversed shoulder arthroplasties. Insufficient bone stock can lead to suboptimal component fixation after revision and therefore early failure.[13,34] Several methods have been described to address glenoid defects in shoulder arthroplasty,[21] depending on their classification, as being contained (central cavitary bone loss), segmental (anterior or posterior wall), or mixed (combination of cavitary and segmental bone loss).[2] When moderate segmental bone loss is present, eccentric reaming can be performed to maximize the contact between the glenoid component and the bone and to restore acceptable version without grafting.

Bone grafts can be used to augment the glenoid defects and to restore the glenoid bone stock when eccentric reaming is not possible. Treatments with corticocancellous autografts from the humeral head or the iliac crest and with femoral head allografts have been described, but the results of bone grafting are controversial because not all studies have reported satisfactory outcomes.[11,19,23,27,31,39] A major concern when using bone grafts is the resorption and subsidence of the graft leading to loosening and early failure.[23,39]

A custom implant allows for adequate reconstruction of the bone defect, and patient-specific preoperative planning and implant design can enable proper joint positioning and fixation of the component in the remaining native bone.[3,9,10,41] Berger et al[3] described the use of a custom glenoid component for the treatment of a large glenoid defect in the setting of reverse shoulder arthroplasty. We recently published a case of a revision of the glenoid component of an anatomic total shoulder prosthesis using a custom glenoid component.[41] In both cases, the component was fabricated using computed tomography (CT) 3-dimensional (3D) reconstructions and computer-aided design. Optimal fixation and positioning of a glenoid component requires perfect visualization and assessment of the glenoid, and this is sometimes difficult due to scarring and contracture of the joint. Detailed CT-based 3D planning can help the surgeon assess the size of the glenoid defect.[39] However, even in experienced hands, the ability to implant a glenoid component as planned is limited in accuracy.[32]

The computer-assisted surgery (CAS) and patient-specific instrumentation (PSI) were successfully introduced to improve the accuracy of glenoid component implantation in anatomic and in reverse shoulder arthroplasty.[12,26,32,44] On the one hand, a major disadvantage of CAS is the increased operating time[26] and that it remains a technically demanding procedure.[12,32] On the other hand, PSI was shown to be advantageous for anatomic and reverse shoulder arthroplasty, and the use of patient-specific guides improved the precision of the placement of the glenoid component.[17,22,29,42,45]

This study aimed to expand these insights and, in particular, to investigate the added value of using patient-specific positioning guides for the reconstruction of severe glenoid defects with custom-made glenoid components. We hypothesized that the use of such a guide would result in a more accurate positioning of the implant and in a better positioning of the fixation screws.

Materials and methods

Study design

The study used 10 fresh frozen cadaveric shoulders (mean age, 79 years). Given the absence of a representative data set to assess variability in the parameters of interest, no power analysis was performed.

Specimen preparation

The presence of glenoid bone defects was assessed using CT scans. Images were taken with the cadaver lying supine with the arms at the side in a 2 × 128-detector CT scanner (Siemens Somatom Definition Flash; Siemens Belgium nv/SA, Beersel, Belgium). The acquisition parameters were 100 kV, mAs calculated based on cadaveric anatomy, 0.6 mm collimation, 512 × 512 matrix, no gantry tilt, and 25-cm field of view. The field of view of each scan included the entire scapula. Images were reconstructed using a semismooth algorithm, B30s, and a semisharp algorithm, B60s, at 1.0-mm increments in the axial plane.

Surgical procedure

All specimens were placed in the beach chair position. The glenoid was accessed through a deltopectoral approach, and a clavicle osteotomy[37] was performed. The rotator cuff was resected to mimic a cuff tear arthropathy to be treated with a reversed shoulder prosthesis. Anterior, posterior, or central glenoid defects were created using a large reamer and a chisel. Maximal glenoid bone loss was pursued by reaming beyond the base of the coracoid process. The integrity of the base of the coracoid process, the scapular spine, and the lateral border of the scapula were maintained, allowing screw fixation beyond the glenoid vault.[7,8,20,24]

Preoperative planning, design, and production of guides and implants

All shoulders were CT scanned after defect creation using the protocol described above. The dedicated commercial software Mimics 14.1 (Materialise NV, Leuven, Belgium), was used to create 3D surface models of all scapulae before and after defect creation. The volume of the defects was quantified, and all defects were classified as central, anterior, or posterior, according to the location of maximal bone loss (Fig. 1). Four shoulders were classified in the central group, 2 in the anterior group, and 4 in the posterior group. The average bone loss was 9.1 ± 2.8 cm^3. For the shoulders that underwent implantation with the guide, the average bone loss was 9.4 ± 2.8 cm^3 (range, 6.7-12.2 cm^3). For shoulders