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Three-dimensional planning and use of patient-specific guides improve glenoid component position: an in vitro study

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Background: Glenoid component positioning is a key factor for success in total shoulder arthroplasty. Three-dimensional (3D) measurements of glenoid retroversion, inclination, and humeral head subluxation are helpful tools for preoperative planning. The purpose of this study was to assess the reliability and precision of a novel surgical method for placing the glenoid component with use of patient-specific templates created by preoperative surgical planning and 3D modeling.
Methods: A preoperative computed tomography examination of cadaveric scapulae (N = 18) was performed. The glenoid implants were virtually placed, and patient-specific guides were created to direct the guide pin into the desired orientation and position in the glenoid. The 3D orientation and position of the guide pin were evaluated by performing a postoperative computed tomography scan for each scapula. The differences between the preoperative planning and the achieved result were analyzed.
Results: The mean error in 3D orientation of the guide pin was 2.39°, the mean entry point position error was 1.05 mm, and the mean inclination angle error was 1.42°. The average error in the version angle was 1.64°. There were no technical difficulties or complications related to use of patient-specific guides for guide pin placement. Quantitative analysis of guide pin positioning demonstrated a good correlation between preoperative planning and the achieved position of the guide pin.
Conclusion: This study demonstrates the reliability and precision of preoperative planning software and patient-specific guides for glenoid component placement in total shoulder arthroplasty.
Level of evidence: Basic Science, Surgical Technique.

Keywords: Total shoulder arthroplasty; patient-specific guides; glenoid component position; computed tomography; 3D; preoperative planning

The Institutional Review Board of the ethical committee of the Hôpital Privé Jean Mermoz and the Centre Orthopédique Santy approved this project (Study 2014-01).

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Glenoid component positioning has been recognized as one of the key factors for success in total shoulder arthroplasty.[23] Implanting the glenoid component without excessive retroversion has been emphasized to avoid instability and early glenoid failure.[4,9,13,17,23,24] Measurement of glenoid retroversion has been shown to be unreliable when it is performed with either axillary radiographs or standard 2-dimensional (2D) axial computed tomography (CT) images.[1,8,10,12] Three-dimensional (3D) reconstruction of the scapula and 3D measurements of glenoid retroversion, inclination, and humeral head subluxation are increasingly recognized as necessary references during the preoperative planning and decision-making process for total shoulder arthroplasty.[5,8,14,15] The major drawback for the orthopedic surgeon is the need for an engineer to perform segmentation of both the scapula and humerus and to manually select several points on the scapula before obtaining 3D reconstruction and 3D measurements of glenoid retroversion and inclination.[2,3,20,21] These steps of 3D reconstruction (segmentation and 3D measurements) may take several hours or days. Thus, these valuable measurements are not readily available for most orthopedic surgeons.

Patient-specific instruments have been proposed to assist the surgeon intraoperatively to reliably reproduce preoperative planning of glenoid component implantation.[6,18] One disadvantage is that this step necessitates the creation of guides by an engineer and typically requires several exchanges between the surgeon and engineer to validate the final design of the guides. Drawbacks of using patient-specific instruments include the additional time and financial burden required for the preoperative planning and manufacturing of the device before surgery.

The purpose of this study was to determine the reliability and precision of placement of a glenoid guide pin with a new preoperative planning software system and associated patient-specific pin guide. The software provides a complete 3D reconstruction of the scapula, measurements of glenoid orientation (version, inclination), virtual implantation of the glenoid component, and generation of a patient-specific guide allowing implantation of a guide pin in the desired orientation. Highly accurate guide pin placement is vital to enable precise glenoid component placement because glenoid reamers and subsequent glenoid component placement are referenced off of the glenoid guide pin.

Materials and methods

Eighteen dry cadaveric scapulae (bilateral specimens from 6 women and 3 men) were obtained from our local anatomy laboratory. The average age of the cadaveric specimens was 78 years. A physical examination excluded any previous disease, fracture, or obvious osteoarthritis. A CT scan of each cadaveric scapula was performed on a Siemens machine (Siemens Healthcare, Malvern, PA, USA). The CT parameters were 140 kV, 180 mAs, and image matrix of 512 $\times$ 512. The field of view was adapted with a maximum of 180 mm, resulting in a pixel size of 0.33 mm. All scapulae were scanned in a dorsal recumbent position with maximum 1.5-mm interval slices. The CT images of each scapula were imported under DICOM (Digital Imaging and Communications in Medicine) format on standard compact discs. The compact discs were introduced into a computer and processed through the Glenosys software (Imascap, Brest, France). This software is able to perform automatic segmentation, 3D reconstruction, and measurements of glenoid retroversion and inclination. It has been demonstrated previously that the Glenosys software measurements have excellent reliability and reproducibility.[11]

Glenosys software

The first step performed by Glenosys planning software is fully automatic segmentation based on 3D shape recognition algorithms applied to each object detected in the volume. The second step is a specific processing that treats only the region between the humerus and the glenoid surface to separate possible contact areas. The third step is a full morphologic analysis of the anatomic structure of the bone. The glenoid surface and the glenoid vault are detected, and 3D version and inclination angles of the glenoid surface are automatically computed. This method determines a new scapular reference plane. It is based on all 3D points of the scapular body, and it is computed by fitting a plane by the mathematical principles of least-squares minimization. The same process is applied to define a glenoid plane: the glenoid surface is detected automatically with a 3D watershed-based method applied on the 3D scapula model. Because the software uses all the points of the scapula and the glenoid, there is no need to manually define any point on the 3D model.

The parameters of glenoid version and inclination are extremely important to define an optimal path for implanting the glenoid guidewire and subsequent glenoid reaming. The surgeon can easily modify the position of the implant in 3 dimensions aided by 3D and 2D views of the patient's anatomy in the software interface. The glenoid version and inclination angles as well as the glenoid vault are computed for each position in real time to help the surgeon evaluate the implant position and orientation.

Preoperative planning with Glenosys software

On opening of the software, the first screen (Fig. 1) shows three images: (1) a 2D axial CT image reformatted to be perpendicular to the plane of the scapula; (2) a 2D coronal CT image reformatted to be parallel to the plane of the scapula; and (3) a 3D reconstruction of the scapula. Glenoid retroversion and inclination are automatically measured as the angle between the scapular and the glenoid planes. Glenoid inclination is automatically calculated as the angle between the transverse axis of the scapula (line between the center of the glenoid and the scapula trigonum) and the glenoid plane.

After validation of these measurements, a second screen appears with the templates of the available glenoid prosthesis