Accuracy of patient-specific guided glenoid baseplate positioning for reverse shoulder arthroplasty

Jonathan C. Levy, MD, Nathan G. Everding, MD, Mark A. Frankle, MD, Louis J. Keppler, BS

Background: The accuracy of reproducing a surgical plan during shoulder arthroplasty is improved by computer assistance. Intraoperative navigation, however, is challenged by increased surgical time and additional technically difficult steps. Patient-matched instrumentation has the potential to reproduce a similar degree of accuracy without the need for additional surgical steps. The purpose of this study was to examine the accuracy of patient-specific planning and a patient-specific drill guide for glenoid baseplate placement in reverse shoulder arthroplasty.

Methods: A patient-specific glenoid baseplate drill guide for reverse shoulder arthroplasty was produced for 14 cadaveric shoulders based on a plan developed by a virtual preoperative 3-dimensional planning system using thin-cut computed tomography images. Using this patient-specific guide, high-volume shoulder surgeons exposed the glenoid through a deltopectoral approach and drilled the bicortical pathway defined by the guide. The trajectory of the drill path was compared with the virtual preoperative planned position using similar thin-cut computed tomography images to define accuracy.

Results: The drill pathway defined by the patient-matched guide was found to be highly accurate when compared with the preoperative surgical plan. The translational accuracy was 1.2 ± 0.7 mm. The accuracy of inferior tilt was 1.2° ± 1.2°. The accuracy of glenoid version was 2.6° ± 1.7°.

Conclusion: The use of patient-specific glenoid baseplate guides is highly accurate in reproducing a virtual 3-dimensional preoperative plan. This technique delivers the accuracy observed using computerized navigation without any additional surgical steps or technical challenges.

Level of evidence: Basic Science, Surgical Technique.

Keywords: Reverse shoulder arthroplasty; glenoid baseplate; patient specific; 3D computed tomography

Proper glenoid component positioning is critical for the success of shoulder arthroplasty. This has been shown for both total shoulder arthroplasty and reverse shoulder arthroplasty. In the setting of reverse shoulder arthroplasty, the position of the glenoid component defines the glenohumeral articulation and has a direct influence on impingement points, humeral lengthening and offset, scapular notching, and component stress at the bone-prosthetic interface. Improper glenoid baseplate positioning has been shown to be a contributing factor in
catastrophic failures, scapular notching, and even creation of a stress riser influencing base-of-the-acromion fractures.

For patients requiring reverse shoulder replacement, positioning of the glenoid component can be challenging because of a variety of issues related to patient anatomy and surgical technique. Scarred soft tissue planes from previous surgery, complex patterns of glenoid and scapular bone loss, joint contractures, and loss of reliable anatomic landmarks are commonly encountered in this patient population. Abnormal glenoid morphology has been seen in approximately 40% of cases, and in these cases, placement of the glenoid component along the anatomic center line may not be possible. In these situations, directing the glenoid baseplate along an alternative axis at the base of the scapular spine may be required, which can be a difficult intraoperative task. Surgical planning for patients undergoing reverse shoulder replacement can be improved using 3-dimensional (3D) reconstructions of computed tomography (CT) scans, which help to better understand the complexities of scapular anatomy. However, re-creating the surgical plan at the time of surgery can be difficult.

Computer-assisted navigation provides an opportunity to improve the accuracy of reproducing the surgical plan for reverse shoulder replacement. In a cadaveric study of glenoids without deformity, CT-based navigation helped to improve the accuracy of glenoid baseplate implantation when compared with traditional surgical techniques, achieving accuracy within 2° for reproducing inferior tilt and within 8° of planned glenoid version. Similar improvements in the accuracy of glenoid component implantation have been observed using navigation for total shoulder arthroplasty. However, computer-assisted navigation for shoulder surgery can be technically demanding, with challenges related to array fixation and other technical problems resulting in aborting the navigation technique, as well as an increase in operative time by more than 20%. Patient-matched instrumentation has the potential to provide similar accuracy to computer-assisted navigation without the challenges related to increased surgical time and technical issues related to intraoperative setup. This has been demonstrated for total shoulder arthroplasty, but not for reverse shoulder arthroplasty. The purpose of this study was to examine the accuracy of patient-matched instrumentation for reproducing a surgical plan used for reverse shoulder arthroplasty.

**Materials and methods**

A patient-specific planning and guiding system was developed for glenoid implant placement in reverse shoulder arthroplasty procedures (SurgiCase Connect; Materialise, Leuven, Belgium). This system allows for preoperative planning on a patient-specific virtual 3D model of the scapula derived from thin-cut CT images. CT scans were performed on 14 cadaveric shoulder specimens using 1-mm axial slices, a slice increment of less than 0.625 mm, and a field of view covering the entire scapula. These CT images were imported into the surgical planning system.

An anatomic coordinate system was created to measure version and inclination based on anatomic landmark points. The scapular plane was defined by the glenoid center point, the inferior scapular angle point, and the trigonum spinae point. The glenoid center point was determined by selecting the smooth surface of the glenoid face and calculating its center (Fig. 1A). A plane was fit to the selected glenoid face surface to create the glenoid face plane. A neutral inclination axis was defined between the glenoid center point and the trigonum spinae (Fig. 1B). Inclination was thus measured with respect to the neutral axis, and version was measured with respect to the scapular plane.

Virtual surgical planning was performed by the surgeon using software that allowed the definition of a surgical plan (Fig. 2A) for the glenoid baseplate component of the DJO Surgical Reverse Shoulder Prosthesis (DJO, Austin, TX, USA). This baseplate design uses a central screw that requires a single-axis definition for surgical planning. From this surgical plan, patient-specific surgical guides were created. The guides were designed to fit onto the exposed anatomy’s surfaces, which represented bony or worn regions requiring minimal additional exposure. The drill cylinder was positioned to guide the drilling of a 2-mm Kirschner wire along the axis path for the planned glenoid baseplate (Fig. 2B).

High-volume shoulder surgeons then performed the surgical procedure on the 14 cadaveric specimens. By use of the standard technique for implantation of the DJO Reverse Shoulder Prosthesis, a deltopectoral approach was used to facilitate glenoid exposure. The patient-matched guides were then placed onto the glenoid face, and Kirschner wires were drilled across both cortices of the glenoid.

Once the drill paths were created, “postsurgical” CT scans were performed using the same CT scanning protocol. Virtual bone models were then created using the same methods used for preoperative planning. The drill paths observed on postsurgical CT scans were segmented, and best-fit cylinders were created for each drill path. The preoperative scapula and planned drill position were then aligned to the drill paths observed on the postsurgical scans. Angular deviations were measured between the planned and measured drill paths in the coronal and axial planes, as well as the 3D angle. Translational errors were taken from the measured entry point on the glenoid face to the planned drill path. Translational errors were projected into the sagittal and axial planes.

**Results**

A total of 14 drill paths were studied in the 14 cadaveric specimens, representing the trajectory of the glenoid baseplate based on the surgical plan. The ability to reproduce the surgical plan was highly accurate. The translational accuracy of the pin tracts was 1.2 ± 0.7 mm from the surgical plan, with a maximum error of 2.1 mm and a minimum of 0.2 mm. The accuracy of reproducing the planned inferior tilt was 1.2° ± 1.2°, with a maximum error of 4.7° and a minimum of 0.1°. The accuracy of reproducing the planned glenoid version was 2.6° ± 1.7°, with a maximum error of 8.4° and a minimum error of 0.1°.
Discussion

Efforts at improving a surgeon’s ability to accurately place a glenoid component continue to evolve. It has been established that traditional methods of glenoid implantation by highly trained shoulder surgeons using modern surgical techniques and instrumentation are limited in accuracy. Errors found with these traditional methods have been shown to be up to 7° of version for total shoulder arthroplasty and 12° of version for reverse shoulder arthroplasty. To better improve the accuracy of glenoid component implantation, computer-assisted navigation and patient-specific instrumentation were developed.

Studies using computer-assisted navigation for shoulder arthroplasty have shown improvements in the accuracy of glenoid component implantation when compared with...
traditional methods. In a cadaveric study, Nguyen et al. reported nearly a 6° improvement in the accuracy of glenoid implantation when navigation was used for total shoulder arthroplasty, and the surgical accuracy improved to within 1.5° of the surgical plan. In a clinical study of 27 patients using navigation, Edwards et al. found that the accuracy of glenoid component implantation was within 2.6° of the surgical plan. In the only reported study using computer-assisted navigation for reverse shoulder arthroplasty, Verborgt et al. reported advantages in using navigation over traditional surgical techniques, improving the accuracy of the surgical plan for inferior tilt and glenoid version to within 8°.

Although the accuracy of reproducing the surgical plan for shoulder arthroplasty improves with computer-assisted navigation, the intraoperative technical challenges of navigation have been shown to increase surgical time. Navigation for glenoid implants requires additional surgical steps not typically performed during shoulder arthroplasty, such as placement of arrays in the scapula and validation of points on the glenoid. In a randomized trial of 20 patients treated using navigation and traditional techniques for total shoulder arthroplasty, Kircher et al. reported improved accuracy using navigation, re-creating glenoid version to an average of 3.7°. However, in 6 patients in the navigation group, the procedure was aborted because of technical problems, and the surgical time for navigation was 20% longer than that for the traditional technique.

Patient-specific instruments have the potential to improve the accuracy of reproducing the surgical plan without the challenges associated with intraoperative navigation. For glenoid implants, the axis of implantation defines the proper starting point on the glenoid, as well as correct version and inclination. This axis can be reproduced by producing a patient-specific drill guide that helps define this axis during surgery. When this drill guide is used, no additional or unfamiliar surgical steps are used during glenoid preparation. The use of patient-specific instruments for shoulder arthroplasty was first reported for total shoulder arthroplasty. In a prospective randomized study of 31 patients, Hendel et al. showed that preoperative surgical planning and patient-specific instrumentation helped to accurately execute the surgical plan required to restore more normal glenoid anatomy. They reported that patient-specific instrumentation was most useful in patients with excessive retroversion, in whom the accuracy of glenoid component implantation improved to 1.2°.

This study is the first to use patient-matched instrumentation in the setting of reverse shoulder arthroplasty. The patient-matched instrumentation used in this study was found to be highly accurate at reproducing the surgical plan for placement of the glenoid baseplate for reverse shoulder replacement as defined by the virtual templating software. With translational accuracy of 1.2 mm, accuracy of inferior tilt of 1.2°, and accuracy of glenoid version of 2.6°, the reproducibility of the surgical plan compares favorably with the historical reports of computer-assisted navigation in both total shoulder and reverse shoulder arthroplasty. In contrast to computer-assisted navigation, patient-matched instrumentation does not require placement of intraoperative arrays, confirmation of anatomic landmarks, and additional surgical time and does not lead to the fracture risk associated with array placement on the scapula, which incurs increased stress after reverse shoulder arthroplasty. Although the patient-specific guides require sufficient surgical dissection to place the guides accurately, the time required is likely less than the 20% increase in time seen with computer-assisted navigation.

The value of patient-specific instruments validated in this study rests in the ability to reproduce the surgical plan accurately and efficiently. As a more precise understanding of the ideal glensphere placement is defined, the clinical relevance of accurate component placement will be defined. The added cost of this technology will ultimately be judged against the value it provides in assisting surgeons more accurately implant glenoid components in reverse shoulder arthroplasty. Further investigation into the reproducibility of these findings in clinical studies, the influence of surgeon experience on guide accuracy, and the degree of accuracy necessary to improve clinical results and, ultimately, a cost-benefit analysis are warranted.

### Conclusion

Surgical planning using virtual models of patient CT scans and the use of corresponding surface-matched drill guides provides an accurate method of reproducing the surgical plan for glenoid component placement in reverse shoulder arthroplasty.

### Disclaimer

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### References


