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SHOULDER

Use of a custom alignment guide to improve glenoid component position in total shoulder arthroplasty

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Abstract

Purpose Total and reverse total shoulder arthroplasty (TSA) are used to treat patients with glenohumeral joint osteoarthritis. The revision rate remains high compared with hip and knee arthroplasty. Glenoid component loosening is an important complication and may be caused by poor positioning of the component. We aimed to evaluate the safety and accuracy of a custom glenoid jig created using preoperative computed tomography (CT) imaging with 3D modelling for glenoid component implantation.

Methods Preoperative CT scans of each shoulder ($N = 7$) were obtained. Implants were virtually aligned and custom templates were created for intraoperative use. A two-part custom jig was manufactured for alignment of the central peg and the peripheral screws. Three-dimensional orientation of the component and screws was evaluated in postoperative CT scans. The difference between the preoperative plan and the result was then calculated.

Results No technical difficulties or complications occurred. The mean absolute difference between the planned alignment and the postoperative placement of the glenoid component in the three-dimensional space was 3.4 mm (SD = 1 mm). The total average difference for all screws ($N = 10$) was 6.3° (SD = 3.2°).

Conclusion A CT-based custom glenoid component alignment can reliably guide the placement of the glenoid component during conventional and reverse TSA. This custom jig may be useful for optimizing glenoid component position in the setting of reverse and TSA.

Level of evidence IV.

Keywords Total shoulder arthroplasty · Reverse total shoulder arthroplasty · Custom jig · CT planning

IRB: Approved by Institutional Review Board of Hospital for Special Surgery (#10144).

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Introduction

Total shoulder arthroplasty (TSA) aims to relieve pain and improve function in patients with glenohumeral joint disease. Due to the inherent design of TSA prostheses, concomitant rotator cuff pathology affects the outcome of TSA [9]. Reverse total shoulder arthroplasty has evolved as a viable option for treating patients with glenohumeral joint arthrosis and massive rotator cuff tears [1, 2, 14, 17, 18, 25, 28, 29].

However, revision rates for standard and reverse total shoulder arthroplasty (4 and 22 % at 10 years, respectively) remain high compared with total knee and hip arthroplasty [1, 12]. Furthermore, the glenoid remains the most common cause of revision surgery for TSA, with the need for revision of the humeral component often related to glenoid component issues [1, 5, 13]. Insufficient instrumentation for the glenoid results in component malalignment, causing loading conditions which may promote accelerated wear and/or loosening [3]. In addition, obtaining sufficient initial fixation particularly for the glenoid component is critical for long-term clinical success [17, 21]. Glenoid component loosening typically occurs within the first 1–3 years postoperatively, and is due to the component being insecurely anchored [19, 25]. Reasons cited for this failure include the lack of formation of new bone below the glenoid baseplate [14], glenoid bone deficiency and poor positioning of the glenoid component on the glenoid surface [25].

Computer navigation technology has been applied to shoulder arthroplasty with improved accuracy in glenoid component placement compared with conventional techniques [23, 27]. However, all previously reported computer-assisted glenoid implantation techniques have employed an intraoperative tracking system [10, 23, 26, 27]. Disadvantages of this approach include: instrumentation that remains cumbersome to use in this anatomic region; the use of pins that may cause fracture or neurovascular injury; registration of anatomic landmarks that may be inaccurate and that adds considerable time to the case; and tracking devices that may loosen, giving unreliable information. As an alternative, we have developed a computed tomography (CT)-based custom jig to guide glenoid component placement, which has the main advantage of placing the power of computer assistance into the preoperative arena and out of the operating room.

Our hypothesis was that a CT-based preoperative plan for glenoid component placement could be successfully achieved during shoulder arthroplasty procedures by using a custom-made guide. The goal of this study was to evaluate the postoperative alignment of the glenoid component in the first series of patients operated on using this novel glenoid component alignment guide.

Materials and methods

This study was performed with the approval of our institutional review board (Hospital for Special Surgery; IRB # 10144). This was a series of ten consecutive patients with glenoid deficiency who underwent conventional ($N = 6$) or reverse ($N = 4$) TSA performed by a single surgeon between February and September of 2009.

Custom glenoid jig design

Prior to surgery, CT scans of each shoulder were obtained. Using the CT data, 3D bone models of the scapula were created using MIMICS (Materialise, Leuven, Belgium). The bone quality of the scapula was visually inspected by both the engineer and the surgeon. Areas of optimal bone quality were identified as those areas that would provide adequate, circumferential coverage of the central peg (in conventional and reverse TSA) and the peripheral screws (in reverse total shoulder arthroplasty). 3D CAD models of the glenoid component were imported and the surgeon verified their position on the glenoid surface (Fig. 1). Based on this preoperative plan, custom glenoid component alignment guides were manufactured from a high-grade, FDA-approved plastic (Duraform™ Polyamide, DTM Corp., Silver Spring, Maryland) to conform to each individual patient's glenoid and with holes to guide the central wire and screws into the pre-identified target areas (Fig. 2a, b).

Surgical technique

A standard deltopectoral approach was employed for both conventional and reverse TSA procedures.

Conventional total shoulder arthroplasty

The glenoid was circumferentially exposed and the custom jig was fit onto the glenoid and the central screw hole was created. The glenoid was then reamed and peg holes were placed in a three-peg configuration. Stability of the trial implant was confirmed and the final implant was then placed and cemented. Biomet Comprehensive® Shoulder System implants (Biomet Orthopedics, LLC, Warsaw, IN) were used for all conventional TSA cases.

Reverse total shoulder arthroplasty

The humerus was retracted posterior and inferiorly, and the glenoid was circumferentially exposed, and the first custom guide was used to place a central guidewire into the metaglene. The glenoid was then reamed and the second custom guide was used to identify and drill the holes for the peripheral screws into the appropriate areas. The metaglene was then impacted into place (Fig. 2c, d). Biomet Comprehensive® Reverse Shoulder System (Biomet Orthopedics, LLC, Warsaw, IN) implants were used in three cases and the Depuy DELTA XTEND™ Reverse Shoulder

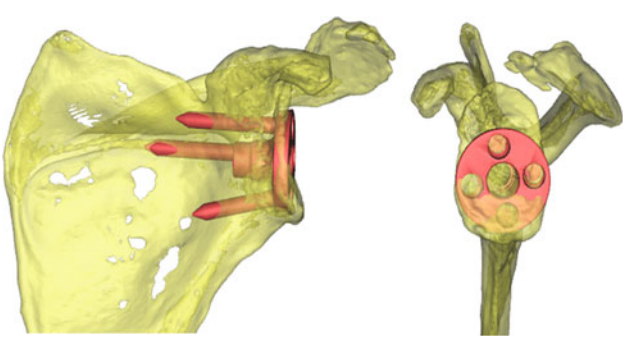

Fig. 1 Anterior and medial views of the 3D model of the scapula used to plan the position of the implant. Prior to the operation, the surgeon can adjust the placement prosthesis to obtain optimal alignment and bone purchase

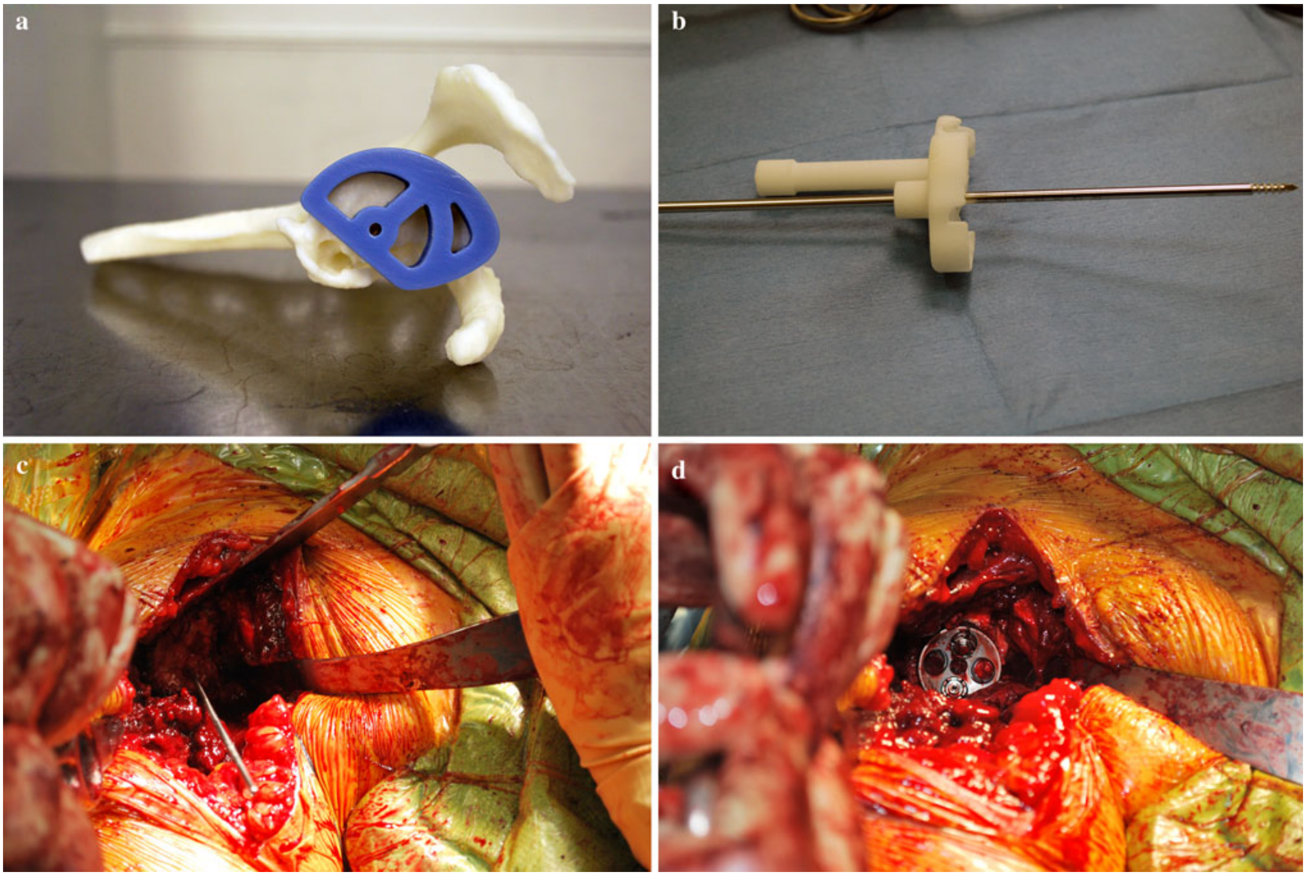

Fig. 2 **a** Duraform™ Polyamide models of the scapula and of the patient-specific guide for preoperative visualization. **b** Sterile guide with central guidewire. **c** Guidewire placed into glenoid using custom guide. **d** Glenoid component is fixed to the bone

System (DePuy Orthopaedics, Inc., Warsaw, IN) was used in one case.

Postoperative evaluation

Postoperatively, we compared 3D models constructed from CT scans of the patients' shoulders (with the implant in place) against the previously constructed 3D preoperative plans. CT imaging was performed 1 month after the operation. Using MIMICS, we segmented out the glenoid component from the scapula and created a 3D model of the scapula and a 3D model of the glenoid component. Using Geomagic (Geomagic, Research Triangle Park, NC, USA), we matched the postoperative coordinate system to the preoperative coordinate system. The registration results were imported into Pro/ENGINEER (PTC, Needham, MA). We established planar orientations of the scapula in the AP, lateral and superior directions, and created reference planes, axes and a centre point on the glenoid component. Then, we calculated the distance between the preoperative and the postoperative centre points in three dimensions. We also calculated the overall distance and the difference in version, inclination and rotation of the glenoid components using created reference planes. To evaluate the placement of the screws in reverse total shoulder cases, the preoperative and postoperative models of the components were matched in the same coordinate system. We then calculated the angle resulting from the divergence of each screw from its planned trajectory in three-dimensional space. Two examiners performed the measurements, with an ICC of 0.97.

Results

A total of three conventional and four reverse TSA cases were reviewed. Three cases were excluded from this evaluation as no postoperative computed tomography (CT) data was available. There were five female patients and two male patients, with a mean age of 66 years (SD = 6.6 years) and a mean BMI of 28.3 (SD = 5.3).

Glenoid component orientation

The absolute difference between the planned alignment and the postoperative placement of the glenoid component in the three-dimensional space was a mean 3.4 mm (SD = 1 mm) (Fig. 3). The mean difference in the antero-posterior direction was 0 mm (SD = 1.7 mm). In the superoinferior direction, the mean difference was 1.7 mm more superior (SD = 2.1 mm). And there was a mean lateral placement of the metaglene of 1.3 mm (SD = 1.4 mm).

The glenoid component had a mean 0.2° (SD = 8.2°) more superior inclination compared with the plan and a mean 3.4° more retroversion (SD = 7.2°). Since glenoid components in TSA do not require long screws and rotation is not an issue, we analysed the variability in baseplate rotation only in reverse total shoulder cases, for which there was a mean forward rotation of 6.76° (SD = 6.5°) compared with the plan. The absolute angular difference between the planned and the final glenoid position for the reverse total shoulder cases was a mean 9.1° (SD = 6.6°).

Screw orientation

Superior and inferior screws were used in all four reverse total shoulder cases, whilst a posterior screw was used in two cases. Average difference between the superior screw and the preoperative plan was 6° (SD = 2.4°). For the inferior screw, the difference was 6.1° (SD = 3.5°). And, for the posterior screw, the mean difference was 7.6° (SD = 6.1°). The total average difference for all screws ($N = 10$) was 6.3° (SD = 3.2°).

Discussion

The most important finding of the present study was that the custom shoulder jig was successfully used intraoperatively and without technical difficulties or complications

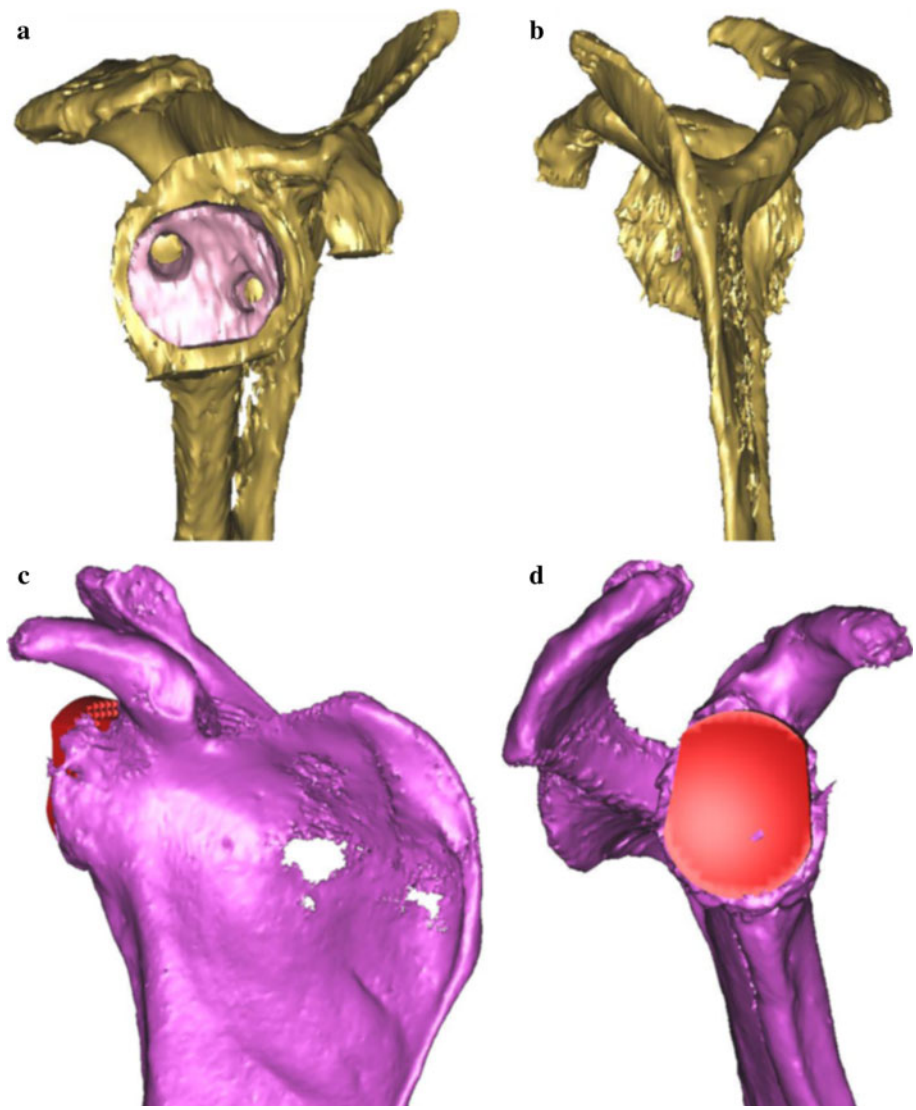

Fig. 3 Postoperative 3D reconstructions showing excellent placement of the glenoid component in one case of reverse TSA (**a**, **b**) and one case of conventional TSA (**c**, **d**)

(Fig. 4). Quantitative analysis of glenoid component positioning showed good agreement between the preoperative plan and the achieved position.

Previous studies have shown that natural variations and anatomic changes associated with shoulder joint arthrosis affect implant orientation and fixation [6, 24]. Erosions and irregularities of the glenoid surface present a challenge for the fixation of the glenoid component by the surgeon [15] (Fig. 5). Additionally, the surgical approach commonly used during reverse total shoulder arthroplasty does not always provide adequate visualization of the glenoid face during surgery. Hence, it may be difficult to achieve the desired positioning of the glenoid component fixation screws with the standard instrumentation.

Glenoid version can be highly variable in orientation secondary to eccentric wear from osteoarthritis [4, 7, 20]. Favre et al. [11] recommended avoiding retroversion of more than 10°, as incorrect orientation of the glenoid can lead to early prosthetic wear, instability and mechanical failure [3, 8, 22]. In addition, glenoid positioning may affect postoperative function, as Frave et al. [11] showed that superior glenoid component offset greater than 5 mm caused a loss of more than 5° in maximum glenohumeral elevation angle, whilst a superior glenoid component inclination of 20° completely prevented elevation. Using the custom jigs, we achieved a retroversion difference of 3.4° (SD = 7.2°), a mean superior offset of 1.7 mm (SD = 2.1 mm) and a mean difference in superior inclination of 0.2° (SD = 8.2°) from the preoperative plan. In our reverse total shoulder series, we achieved a mean retroversion angle of 1.8° (SD = 11.1°), which compares favourably with the results reported in other computer-assisted glenoid implantations in the literature. In a series of cases using intraoperative navigation, Kircher et al. [23] reported a postoperative mean retroversion angle of 3.7° (SD = 6.3°), which was significantly better than the non-navigated 15.7° (SD = 5.8°) in control shoulders in their study. Similarly, Edwards et al. [10] achieved 3.0° (SD = 6.3°) of version compared with the native glenoid using an image-free shoulder navigation system in a cadaver. Nguyen and colleagues used an intraoperative tracking system with real-time feedback with a mean glenoid version of 5.2° (SD = 5.0°) [26].

All three previously reported computer-assisted navigation systems for implantation of glenoid components utilize intraoperative tracking. Whilst this system has the advantage of providing real-time feedback to the surgeon, its disadvantages are many. First, the technology has a

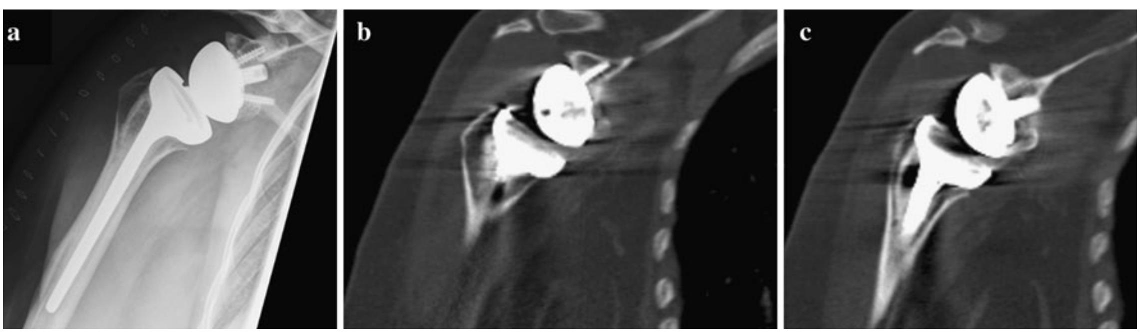

Fig. 4 **a** Radiograph shows proper postoperative alignment of the glenoid component. **b**, **c** Good, circumferential bone coverage was achieved for the central peg and peripherals screws

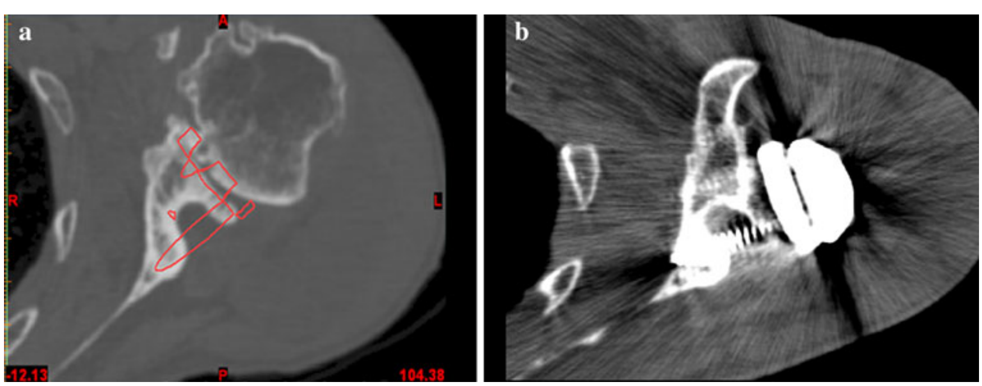

Fig. 5 **a** Preoperative planning of glenoid component position in a patient with severe glenoid bone defect. **b** Postoperative image showing successful postoperative placement of the glenoid component

steep learning curve and can lead to excessively long operative times [10]. The intraoperative tracking devices create a unique set of complications including potential pin site fracture or neurovascular injury from pin site placement. Furthermore, a tracking device can have loosening or unrecognized movement during the case, or anatomic landmarks can be inaccurately registered, leading to poor glenoid component placement [26].

The major limitation of this study is the lack of a control group of conventional jigs to directly compare the results of component alignment. However, the objective of this study was to assess the efficacy of the device by demonstrating its feasibility; by detecting any intraoperative technical difficulties; and by comparing the postoperative placement to the preoperative plan with patients acting as their own controls. Drawbacks of using this device include the additional time and financial burden required to plan the alignment of the component and manufacture the device prior to surgery. Additionally, whilst computer-assisted orthopaedic surgery in the setting of shoulder arthroplasty may achieve more accurate and reliable placement of the glenoid component, this may not necessarily lead to improved patients' outcomes. For example, since the introduction of computer-assisted surgery in total hip arthroplasty over a decade ago, there has been no improvement in dislocation rates, range of motion, function or outcome scores in patients. A recent meta-analysis of 250 patients demonstrates that computer navigation significantly improved the surgeon's ability to place the acetabular cup within the desired alignment, but this improved surgical precision has not clearly translated to improved long-term clinical outcomes [16].

Conclusion

The intraoperative use of a custom-made alignment guide based on preoperative CT-based planning was successfully accomplished. This device may be a useful tool for achieving optimal positioning of the glenoid component during conventional and reverse total shoulder arthroplasty.

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Conflict of interest None of the other authors have any conflicts of interest to disclose.

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