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Treatment of displaced intra-articular glenoid malunion deformity with reverse total shoulder arthroplasty guided by augmented reality-assisted computer navigation

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The position of the glenoid component in total shoulder arthroplasty is important for maximizing postoperative function and long-term survivorship.[13] Proper baseplate alignment allows optimal range of motion, minimizes impingement, and decreases stress on the bone-prosthesis interface.[7] Glenoid malposition is associated with higher rates of implant loosening, instability, early failure, and poor clinical outcomes and is one of the most common complications of reverse shoulder arthroplasty.[14]

Abnormal glenoid morphology, bone loss, or post-traumatic deformity can further complicate the intraoperative implant positioning process. In these scenarios, it is often difficult to determine native glenoid version, inclination and medialization, and the amount of required correction is not always clearly defined.[12] Traditional preoperative planning methods and surgical techniques do not provide a standardized approach to correct moderate to severe glenoid deformity.[6]

The development of new technology within the field of shoulder arthroplasty offers novel solutions to solve complex surgical problems. This case highlights the opportunity for and implementation of a novel navigation system, assisted by augmented reality (AR) images superimposed on the surgical field, allowing precise replication of a complex preoperative 3-dimensional (3D) plan.

Case presentation

The patient is a 64-year-old right hand dominant male laborer who sustained a right comminuted intra-articular glenoid and scapular body fracture after involvement in a motorcycle accident (Fig. 1). After failing to progress with 10 weeks of nonoperative management, the patient underwent open reduction internal fixation at an outside institution through a posterior Judet approach. This ultimately resulted in a displaced intra-articular malunion and was associated with severe pain, restricted passive range of motion, and weakness in both posterosuperior rotator cuff and deltoid musculature 1 year after his open reduction internal fixation. On examination, the patient demonstrated active and passive range of motion limited to 60° forward flexion, 10° external rotation, and internal rotation to the level of his sacroiliac joint. Radiographs and computed tomography (CT) scan obtained 12 months from date of surgery demonstrated malunion of the intra-articular glenoid fracture and intra-articular screw penetration from the posterior plate (Fig. 2). Infection workup in the form of white blood cell, erythrocyte sedimentation rate, and C-reactive protein was negative, and electromyography of suprascapular and axillary nerves demonstrated adequate conduction potential. Given persistent pain, activity-limiting stiffness, and weakness, the patient was

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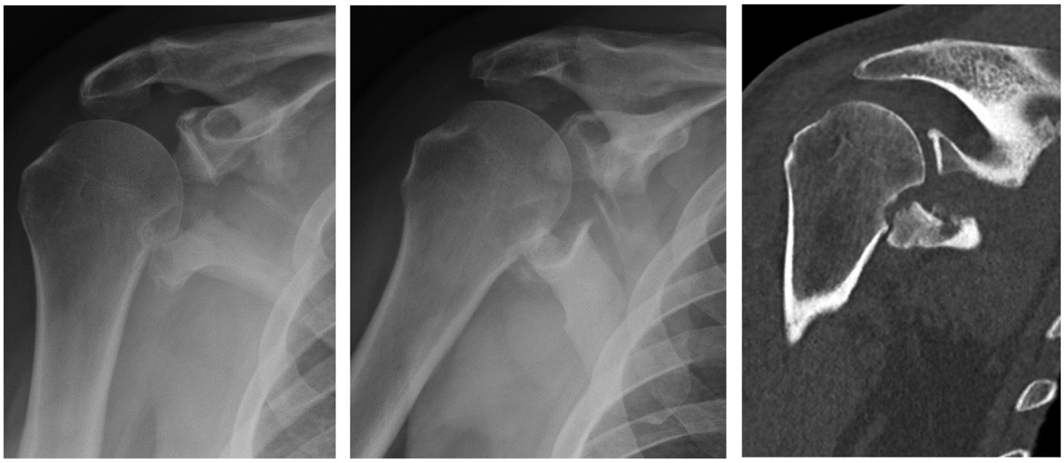

Figure 1 AP and internal rotation radiographs demonstrate glenoid fracture through the midportion with nearly 15 mm diastasis. Coronal CT redemonstrates fracture diastasis and depicts humeral head impaction. *CT*, computed tomography; *AP*, anterior posterior.

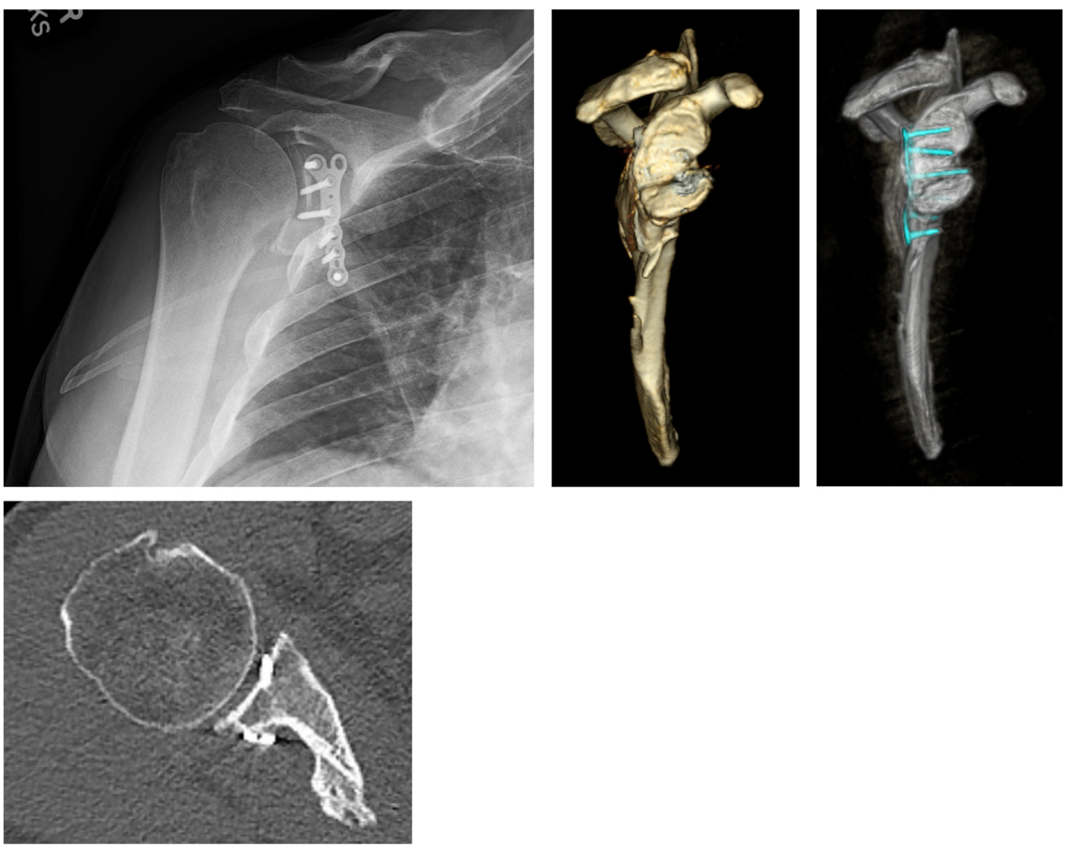

Figure 2 Grashey radiograph, axial CT, and CT 3D reconstructions demonstrate glenoid malunion with intra-articular extension of multiple screws. *3D*, three dimensional; *CT*, computed tomography.

indicated for removal of hardware and conversion to reverse total shoulder arthroplasty.

Preoperative planning

Due to the malunion of both the glenoid and the scapular body, it was clear that the standard visual and tactile reference techniques used during reverse total shoulder arthroplasty would be difficult to apply at the time of surgery, making intraoperative determination of baseplate version, inclination, and medialization imprecise. We decided to use 3D planning software to optimize the position of the baseplate to maximize impingement-free range of motion and baseplate fixation (Fig. 3).

The preoperative plan identified a large posterosuperior glenoid defect with step-off. This defect was too large to correct simply by reaming the inferior glenoid, which would have resulted in excess medialization of the construct. Using the planning software, we determined that a bone autograft would fill the defect nicely and

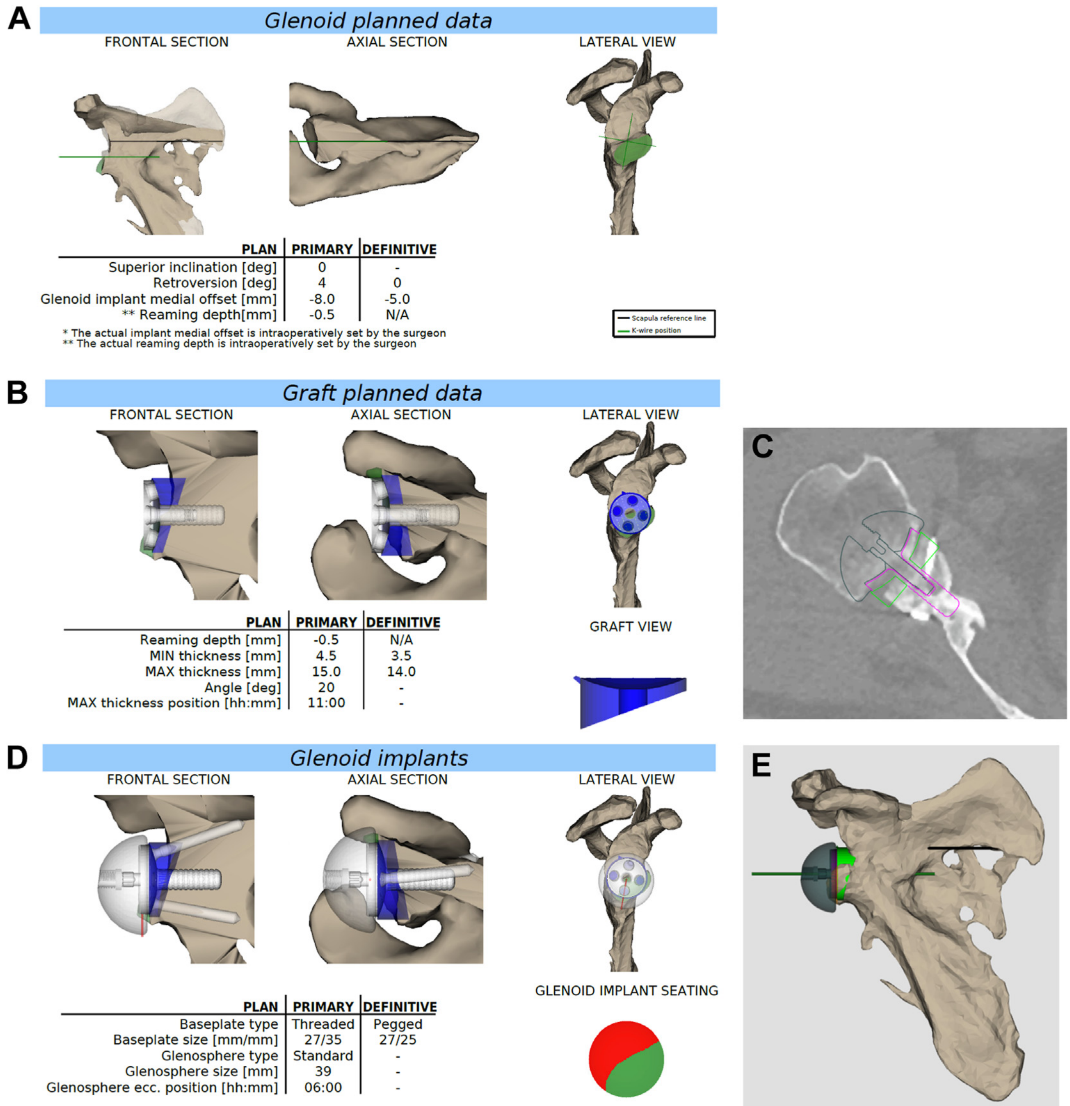

Figure 3 Preoperative plan as determined by NextAR software. (**A**) Large posterosuperior glenoid defect with step-off. (**B**) Templated bone graft with precise thickness and angulation measurements. (**C**) Axial CT of planned peg position within glenoid. (**D**) Glenoid construct with bone autograft augmentation and graphic depicting planned reaming. (**E**) 3D reconstruction of final glenoid construct placement. *CT*, computed tomography.

provide structural support to the glenoid construct while still allowing at least 50% of the backside of the baseplate to rest on native bone. We specified the precise graft thickness and angulation using the software and incorporated this into the plan. To precisely execute this plan, we chose to proceed with intraoperative computer-navigated implant placement assisted by AR glasses.

Technique—removal of hardware

Using a posterior incision, full-thickness medial and lateral skin flaps were developed until the inferior border of the deltoid fascia was encountered. This fascia was opened and the deltoid retracted superiorly. The interval between infraspinatus and teres minor was then identified and incised, exposing the previously placed hardware. The plate and screws were removed, and assessment of the fracture site demonstrated bony union.

Technique—reverse total shoulder arthroplasty

Approach

A standard deltopectoral incision was used to approach the glenohumeral joint. The rotator cuff was inspected, revealing a fibrotic and thin subscapularis and high-grade partial-thickness tear of both supraspinatus and anterior infraspinatus tendons with 90% exposed greater tuberosity. Posterior infraspinatus and teres minor tendons appeared normal.

Bone graft preparation, humerus preparation

Using bone graft harvesting instrumentation matched to the preoperative planning software, the humeral head guide was centered and secured with a bicortical guidewire. The reamer was then used to match the radius of curvature of the glenoid baseplate.

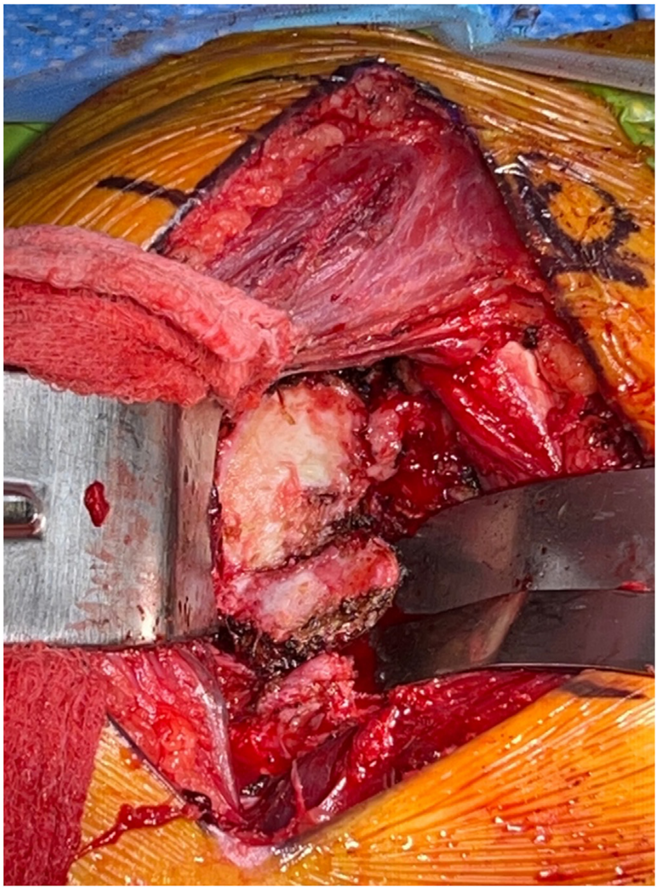

Figure 4 Intraoperative photo demonstrating significant glenoid malunion.

Figure 5 Intraoperative photo depicting NextAR tracker secured to coracoid to allow for calibration between NextAR instruments and preoperative CT scan. *CT*, computed tomography.

The central piston guide and trephine construct were then used to core a graft of the planned thickness. According to the preoperative plan, the graft was cut at 20° and of a thickness to allow 50% of the baseplate to contact the native inferior glenoid (Fig. 3). The humeral shaft was reamed and broached until rotational stability was obtained.

Glenoid preparation and glenoid baseplate placement with augmented reality-assisted navigation

The glenoid was exposed, taking care to identify and protect the axillary nerve. The extent of malunion was examined and found to be significant, as anticipated (Fig. 4). For this case, we used NextAR navigation (Medacta, Castel San Pietro, Switzerland) with Medacta Reverse total shoulder arthroplasty implants (Medacta, Castel San Pietro, Switzerland). The navigation tracker was secured to the coracoid using 2 small pins (Fig. 5). The scapula was then registered to the navigation software using 15 points of reference on the glenoid and 15 on the coracoid. This allowed real-time calibration between the preoperative CT scan, the patient's scapula, and the software.

The optimal start point target was superimposed onto the surgical field and directly visualized through the AR glasses, and the guidewire was advanced to match the templated version and inclination and the glenoid was then reamed to the appropriate depth (Fig. 6). Once the planned reaming depth was achieved, primarily on the inferior malunion fragment, the long peg center hole was drilled. To maximize the likelihood of graft fusion, the superior aspect of the malunited glenoid joint surface graft site was

Figure 6 Concentric glenoid after graft placement and center hole drilling.

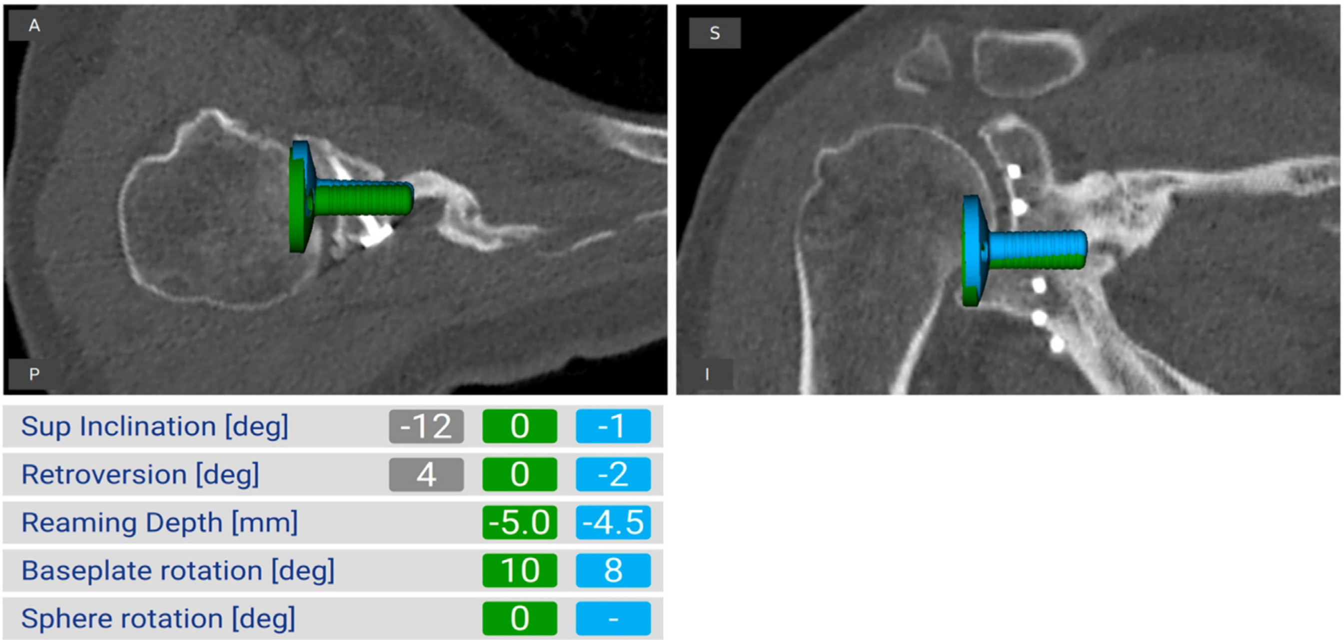

Figure 7 CT scans with superimposed glenoid baseplate, where green represents templated position and blue represents implanted position. This color code is also used to compare preoperative and postoperative measurements (inclination, retroversion, reaming depth, and baseplate rotation). *CT*, computed tomography.

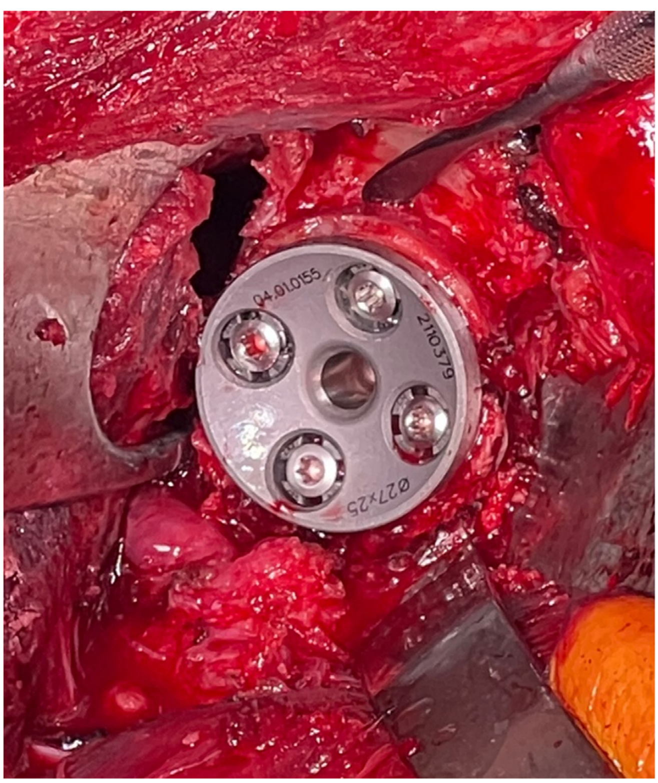

Figure 8 Baseplate fully seated and secured using navigation-assisted screw fixation.

roughened with a bur and the graft was placed superiorly. The baseplate was then impacted into position over the bone graft, and optimal rotation was achieved with AR/navigation assistance (Fig. 7). Excellent press-fit peg fixation was obtained, and additional compression of the graft was provided by variable angle locking screws, also directed with navigation and visualized on CT Digital Imaging and Communications in Medicine images in real time (Fig. 8). A 39-mm glenosphere was rotated under navigation to the offset position maximizing impingement-free range of motion as determined on the preoperative plan.

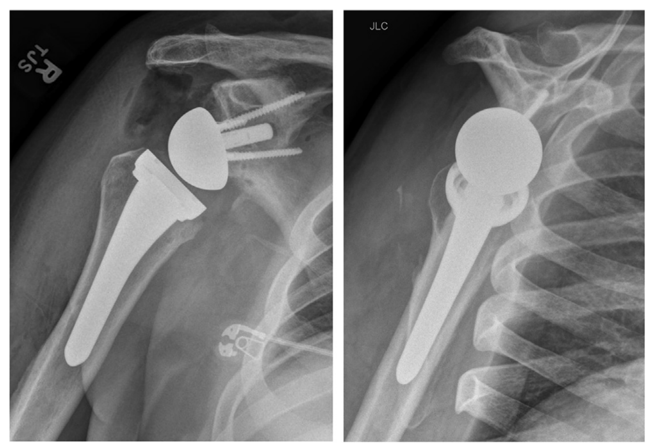

Figure 9 Postoperative AP and scapula Y radiographs demonstrate well-positioned reverse total shoulder arthroplasty with glenoid autograft augmentation.

Humeral stem and polyethylene placement

The humeral component was press-fit and trialed through full range of motion with various polyethylene sizes and neck-shaft angles until the optimal tension, stability, and impingement-free range of motion was achieved.

Postoperative results

The patient's immediate postoperative course was uneventful, and radiographs demonstrated satisfactory position of bone graft and implants (Fig. 9). At 6 weeks, he began formal physical therapy,

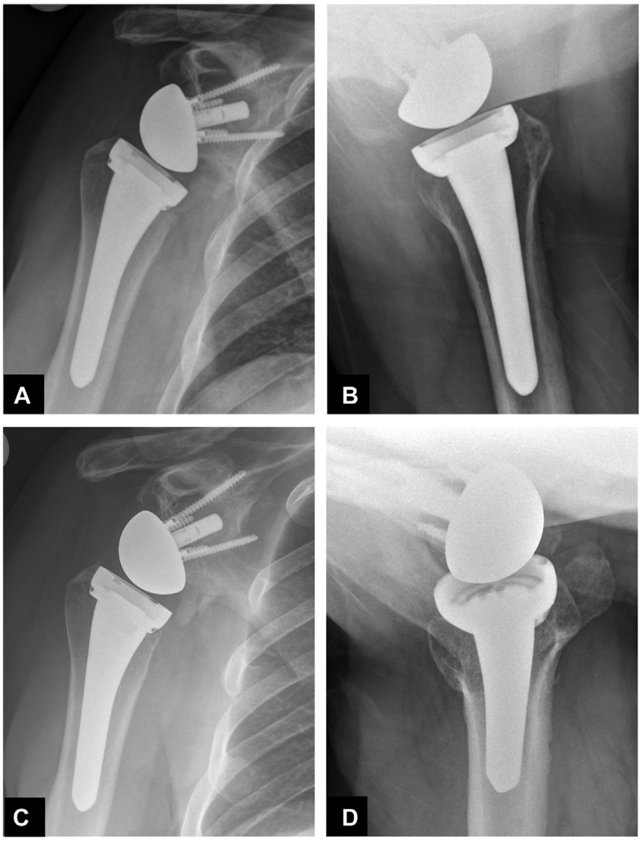

Figure 10 AP and axillary radiographs obtained at 3 (**A** and **B**) and 12 (**C** and **D**) months from date of surgery demonstrate maintained implant alignment without evidence of complication. *AP*, anterior posterior.

Figure 11 Clinical photographs obtained 1 year from date of surgery demonstrate well-healed surgical scars, 150° forward flexion, and 30° external rotation.

and by 12 weeks, his motion had improved to 150° forward flexion and 30° external rotation; internal rotation remained to the level of the sacroiliac joint. Interval radiographs obtained at 3 and 12 months demonstrated maintained implant alignment (Fig. 10). At 1 year from surgery, the patient remained satisfied with the cosmesis, range of motion, strength, and lack of pain associated with his reverse total shoulder arthroplasty (Fig. 11).

Discussion

The importance of glenoid positioning has been well described in the shoulder arthroplasty literature, with malalignment resulting in premature failure and poor clinical outcomes.[14] In cases of significant glenoid deformity, identifying and executing optimal implant positioning in terms of peg position, version, inclination, medialization, and glenosphere offset/rotation represents a significant challenge. Traditional techniques to accurately implant the glenoid baseplate rely on the surgeon identifying visual and tactile landmarks intraoperatively and comparing those to a preoperative 2-dimensional or 3D imaging of the scapula. These conventional techniques have been found to result in higher rates of glenoid component malposition when compared to patient-specific instrumentation (PSI) and computer navigation.[1]

Computer-based 3D preoperative planning has become widespread in shoulder arthroplasty and is especially useful for complex glenoid deformity cases. Standard 3D templating tools reconstruct the scapula to provide a plan that matches patient anatomy with implants to optimize implant size and orientation.[8] These images can then be displayed in the operating room for visualization during surgery, but do not provide any specific guidance or real-time feedback.[9] When intraoperative landmarks are difficult to discern, execution of the preoperative 3D plan can be improved by using additional intraoperative aids such as patient-specific guides, computer navigation, or, as in this case, navigation assisted by AR.

PSI has been designed with the goal of improving glenoid component position, decreasing deviation from preoperative plan, and achieving improved version.[2,3] There is evidence to suggest that use of PSI results in less likelihood for deviation in highly deformed glenoids.[4] While PSIs are thought to optimize glenoid component placement, the degree of improvement and impact on clinical outcomes is still unclear. Recent literature examined patient-reported outcomes, active range of motion, and strength, and compared values between patients having undergone glenoid guide pin placement with standard guides vs. PSI. Although patients in the PSI cohort achieved greater improvement in postoperative strength, there were no significant differences in patient-reported outcomes.[5]

The development of AR-assisted intraoperative navigation software and instrumentation to aid in reverse total shoulder arthroplasty offers a promising solution to expand upon previously used technologies. CT scans have become commonplace for preoperative planning,[12] and this technology offers the ability to directly merge preoperative plans with computer navigation software, which can then be paired with AR hardware.[10,11] AR truly excels in its ability to aid navigation through providing real-time feedback via calibration between instruments and the patient's intraoperative 3D imaging. This allows for image-guided glenoid pin placement, reaming, bone grafting, and baseplate seating. While PSI provides a single, predetermined implant position, AR allows for an infinite number of subtle adjustments as needed.

Additionally, the instrumentation included in the NextAR set is not patient-specific, removing the need for production of custom instruments or physical templates that require additional preoperative processing time. Finally, the precision provided by real-time feedback allows for optimal implant positioning even in the presence of residual soft tissue or severe deformity.[10]

Conclusion

This case demonstrates the successful application of AR-assisted navigation in the treatment of a badly displaced glenoid malunion deformity with reverse total shoulder arthroplasty. The integration of preoperative planning software, nonspecific instrumentation, and real-time AR-guided navigation assistance makes this a promising technology with the potential to improve then execution of shoulder arthroplasty, particularly in challenging cases with severe glenoid deformity.

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Patient consent: The patient provided informed consent for treatment and use of case materials for research purposes.

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