

# Glenoid Component Placement Assisted by Augmented Reality Through a Head-Mounted Display During Reverse Shoulder Arthroplasty



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**Abstract:** Component positioning is a key factor for avoiding complications and improving functional outcomes in reverse shoulder arthroplasty. Preoperative planning can improve component positioning. However, translating the preoperative plan into the surgical procedure can be challenging. This is particularly the case for the glenoid component positioning in severe deformity or limited visualization of the scapula. Different computational-assisted techniques have been developed to aid implementation of the preoperative plan into the surgical procedure. Navigated augmented reality (AR) refers to the real world augmented with virtual real-time information about the position and orientation of instruments and components. This information can be presented through a head-mounted display (HMD), which enables the user to visualize the virtual information directly overlaid onto the real world. Navigated AR systems through HMD have been validated for shoulder arthroplasty using phantoms and cadavers. This article details a step-by-step guide use of a navigated AR system through HMD, in the placement of the glenoid bony-augmented component.

The use of reverse shoulder arthroplasty (RSA) is increasing, and its indications are continually expanding.<sup>1</sup> Accurate component positioning has been

described to be a key factor to avoid complications,<sup>2</sup> achieve better biomechanical performance,<sup>3</sup> and improve functional outcomes.<sup>4,5</sup> Two-dimensional and 3-dimensional (3D) preoperative planning is crucial for accurate intraoperative placement of the glenoid component.<sup>6</sup> Severe deformities and limited exposure of the scapula are some factors that can result in an inaccurate positioning of the glenoid during the surgical procedure.<sup>7,8</sup> Several options have been developed to aid the surgeon in executing their preoperative plan into the surgical procedure. These options include patient-specific instrumentation<sup>9</sup> (PSI), mixed-reality systems,<sup>10</sup> navigation,<sup>11,12</sup> and navigated augmented-reality (AR) systems.<sup>13</sup> The advantages of navigation and navigated AR systems over PSI and mixed-reality systems are that they allow real-time visualization of the plan during the surgical procedure.<sup>14</sup> They also provide immediate and real-time feedback to the surgeon about glenoid component placement.

Navigated AR allows the real world to be augmented with virtual real-time information regarding the position and orientation of instruments and glenoid components.<sup>13</sup> This information may be presented through a head-mounted display (HMD), which enables the user to visualize essential information directly overlaid onto the surgical field. A type of navigated AR through HMD was recently validated for glenoid K-wire

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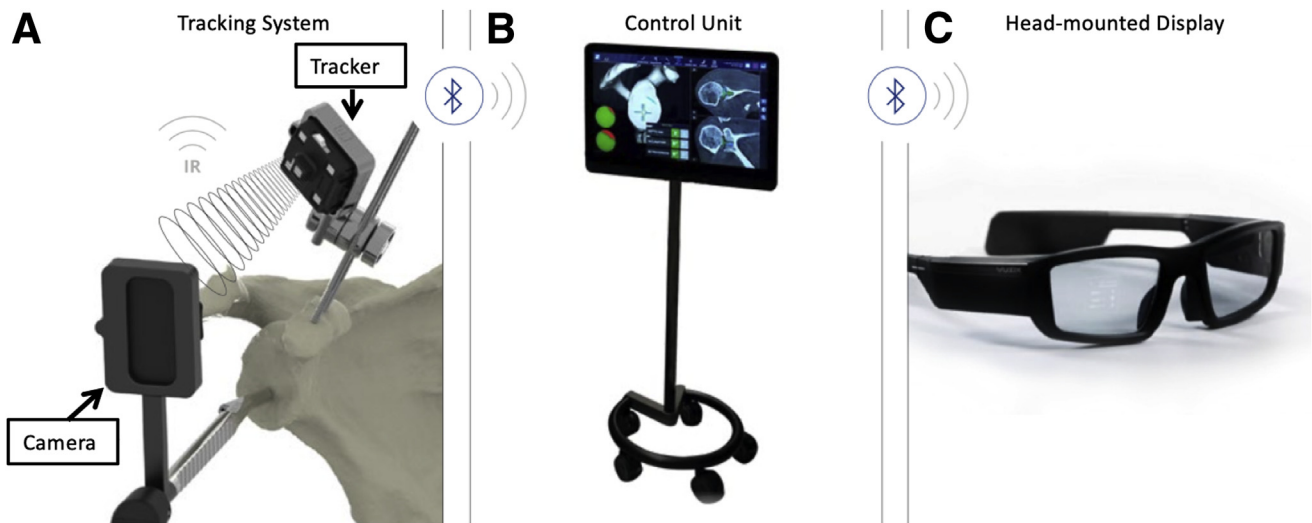
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**Fig 1.** (A) The tracking system (TS) uses infrared (IR) disposable sensors (a tracker and a camera) to track the instrument's position with respect to the anatomical structures in real-time. (B) The control unit (CU) receives information from the TS via Bluetooth and integrates this information with the planning. (C) The head-mounted display receives the information from the CU via Bluetooth. The visualization of the surgical actions superimposed on the operation area allows the surgeon to stay focused on the patient.

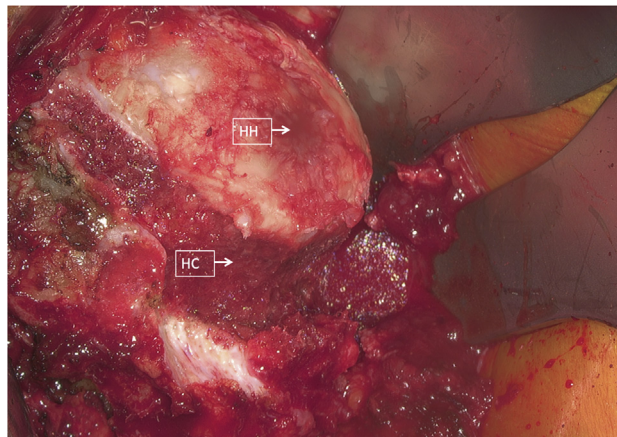
placement in 3D-printed scapula models<sup>15,16</sup> and cadavers.<sup>17</sup> To the best of our knowledge, no technical description of in vivo glenoid component placement with navigated AR system through a HMD has been published. This article aimed to describe a step-by-step glenoid component placement technique using a navigated AR system through HMD in an in vivo setting.

## Surgical Technique (With Video Illustration)

### Preoperative Glenoid Planning

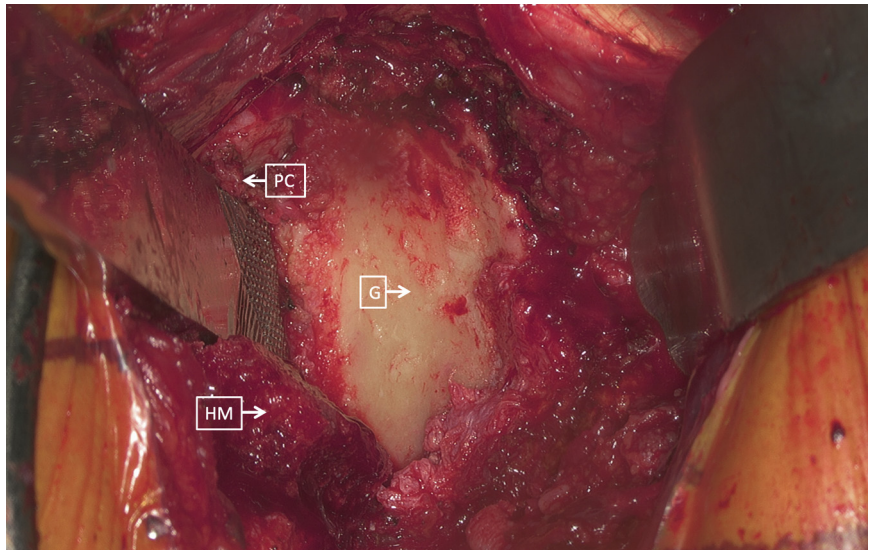
A computed tomography (CT) scan of the scapula and the proximal humerus is required. The CT scan images

are imported using Digital Imaging and Communications in Medicine (DICOM) format to the MyShoulder software (Medacta International, Castel San Pietro, Switzerland). The surgeon then constructs their preferred 3D preoperative plan. The CT scan images and the 3D preoperative plan are then imported to the navigated AR system NextAR (Medacta International). This navigated AR system includes a control unit (CU), which is a medical-grade computer loaded with the patient's complete 3D preoperative plan. The CU receives real-time information from the tracking system that includes a tracker (fixed on the patient's coracoid) and a camera (attachable to the different instruments).



**Fig 2.** Right shoulder, beach-chair position. The humeral capsular release is performed while the humerus is progressively externally rotated until being able to fully rotate and dislocate the humeral head (HH). The osteophytes should be removed until the native humeral calcar (HC) is exposed.

**Fig 3.** Right shoulder, beach-chair position. A posterior capsular (PC) release is essential to reach a wide exposure of the glenoid. For this step, a spreader is recommended between the glenoid (G) and the humeral metaphysis (HM).



This tracking system tracks and sends information to the CU in real time. This position and orientation of instruments and glenoid components in relation to the scapula is visualized via the heads-up display, allowing the surgeon to maintain focus on the surgical field (Fig 1, Video 1).

#### Patient Positioning and Anesthesia

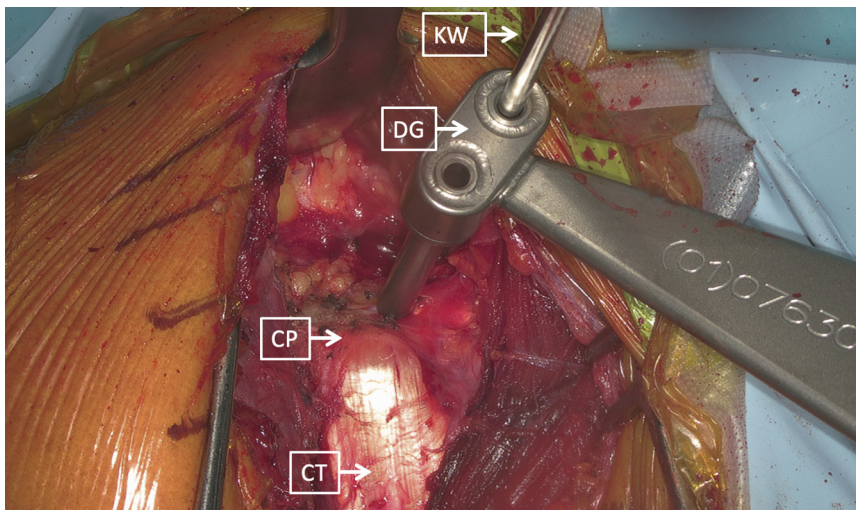
Perioperative antibiotic prophylaxis is administered intravenously 20 minutes before the incision. The procedure is performed with the patient under general anesthesia, with or without an interscalene block, in a semi-beach-chair position. It is necessary to confirm that full extension and adduction of the shoulder is achievable before the preparation and draping of the arm begins.

#### Approach

A standard deltopectoral approach is performed. After marking with electrocautery, a superficial osteotomy of the lesser tuberosity is performed with an osteotome,<sup>18</sup> and the capsular release is completed with electrocautery. Then, the subscapularis is tagged with 2 SutureTape sutures (Arthrex, Naples, FL). The humeral capsular release is then completed in the anteroinferior portion, whereas the humerus is progressively externally rotated until being able to fully rotate and dislocate the humeral head (Fig 2, Video 1).

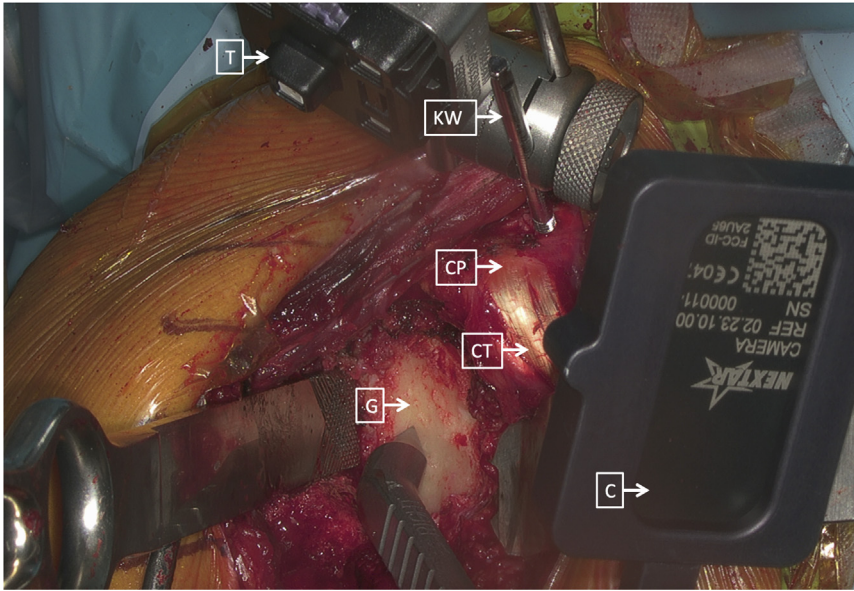
#### Humerus Preparation

The bone graft is harvested before humeral head osteotomy. Using a guide, a K-wire is placed over the humeral head and fixed in the lateral cortex of the



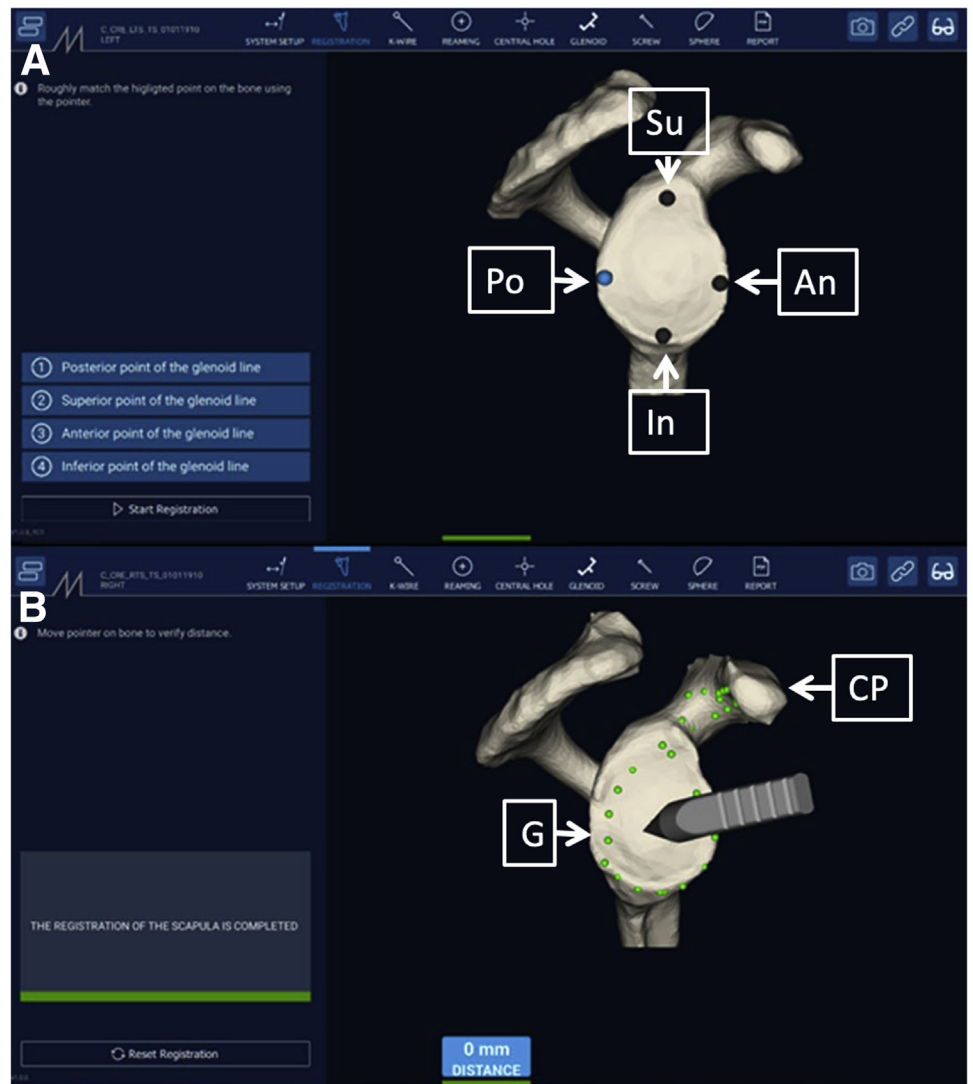
**Fig 4.** Right shoulder, beach-chair position. Using a double guide (DG), 2 K-wires (KW) are placed on the coracoid process (CP), with special caution taken to not hit the conjoint tendon (CT) and inferior structures.

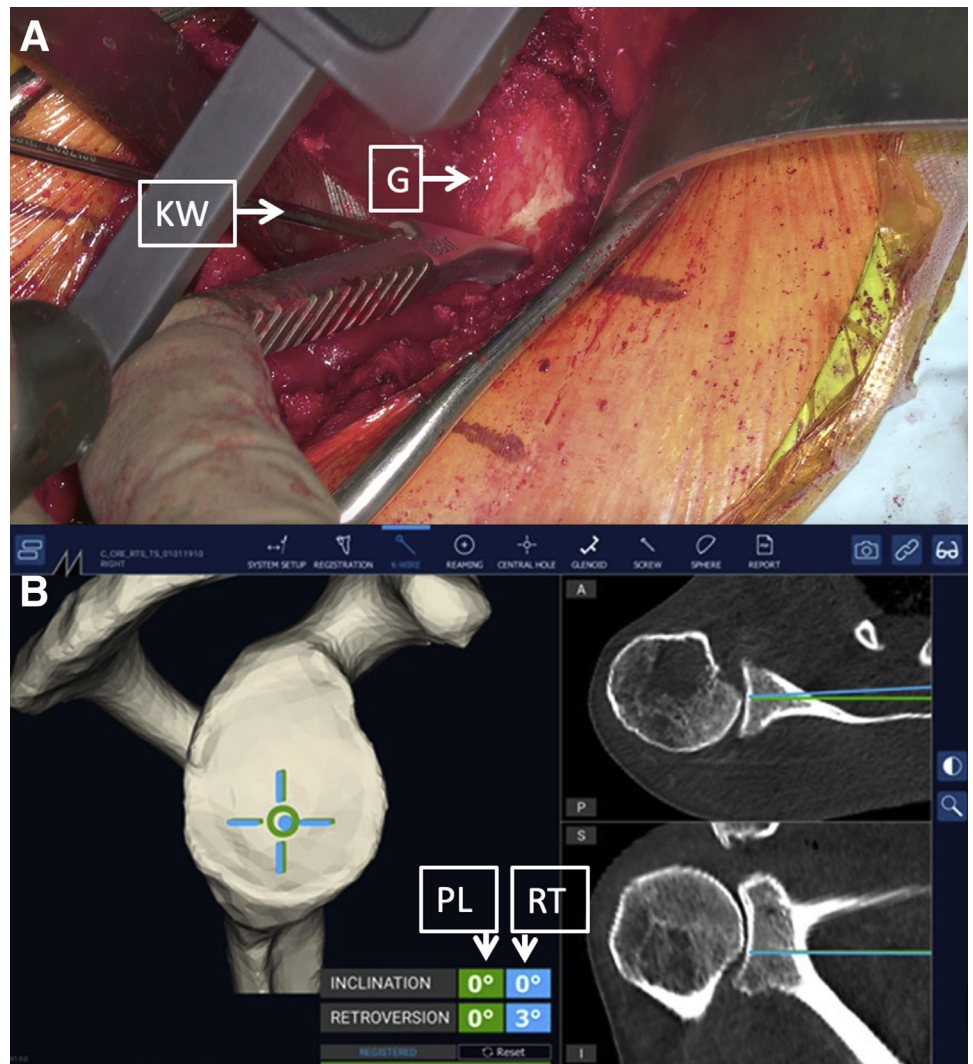




**Fig 5.** Right shoulder, beach-chair position. The tracker (T) is then placed and fixed on the K-wires (KW) onto the coracoid process (CP), in line with the camera (C) placed in the different instrumentations. (CT, conjoint tendon; G, glenoid.).

**Fig 6.** (A) A rough orientation of the system is made marking four points on the posterior (Po), superior (Su), anterior (An), and inferior (In) borders of the glenoid. (B) The glenoid registry is completed placing 30 points around the glenoid (G) surface and the coracoid process (CP).





**Fig 7.** (A) Right shoulder, beach-chair position. The glenoid K-wire (KW) is placed using the specific guide. (B) The navigated augmented reality system gives the surgeon the planned (PL) and real-time (RT) insertion points, alignment and the inclination and retroversion values. On the right side of the image, 2-dimensional computed tomography scan images show the PL (green line) and RT (blue line) direction in the axial (superior) and coronal (inferior) planes. (G, glenoid.)

humerus, with caution not to penetrate the lateral cortex excessively due to the proximity of the axillary nerve. Through the K-wire, a reamer is used to remove the remaining cartilage of the humeral head until the diameter of the planned bone graft is achieved. The circumferential cut of the graft is made using a trephine until the planned depth. The central peg hole is then drilled.

Using a standard cutting guide, a  $135^\circ$  inclination osteotomy with the desired retrotorsion is performed with an oscillating saw. Humeral canal preparation is then performed using progressively larger reamers and broachers. Finally, a cut protector for the metaphyseal bone is put in place before undertaking glenoid preparation.

### Glenoid Preparation

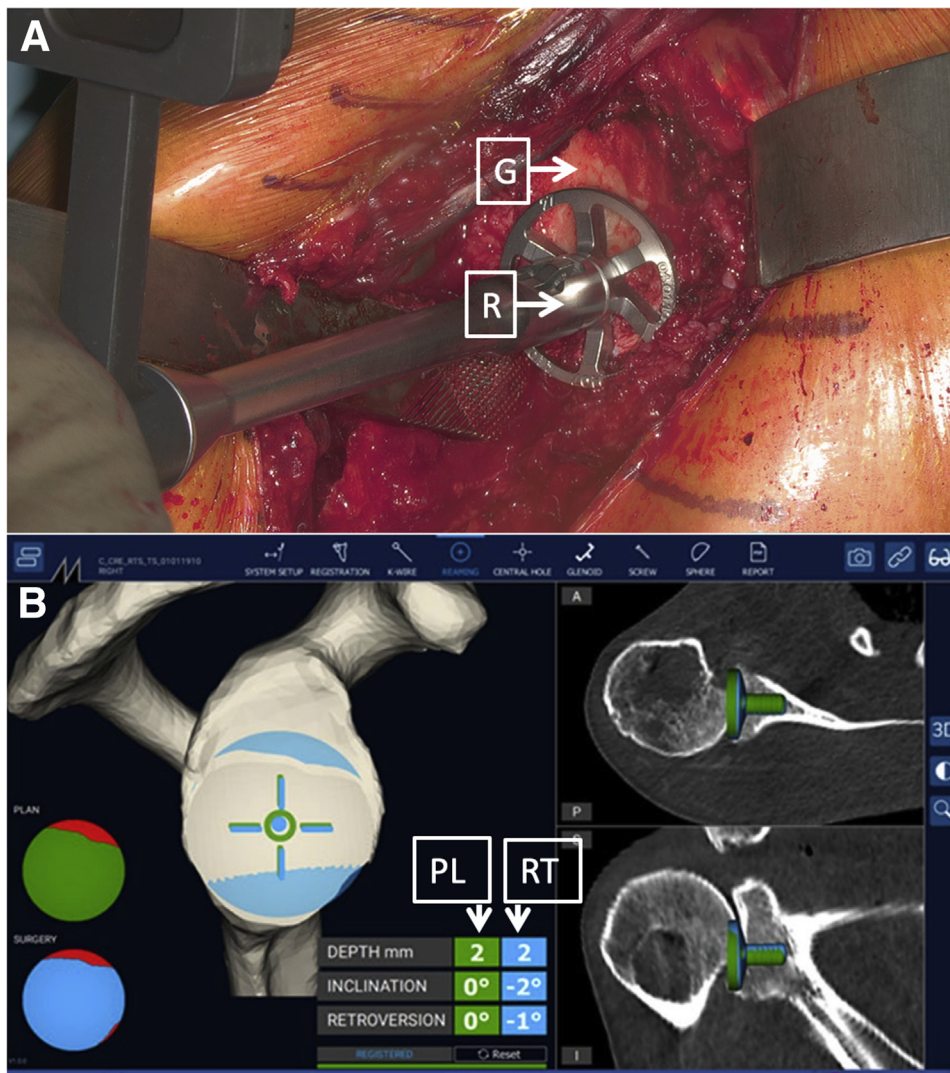
A circumferential release of the labrum and a  $270^\circ$  capsulotomy is performed to achieve an adequate

glenoid exposure. To allow for a complete posterior dislocation of the head, a careful posterior capsulotomy and capsulectomy can be performed, with the help of a lamina spreader between the glenoid and the humeral metaphysis (Fig 3, Video 1). Removal of the cartilage to the underlying subchondral bone is achieved with a curette.

### Coracoid Tracker Placement

A blunt Hohmann retractor is used to expose the coracoid adequately. The coracoid process body and tip should be identified. Using the double guide, 2 K-wires are placed into the coracoid process, taking particular caution not to violate the inferior structures (Fig 4, Video 1). If the patient has a small coracoid, the posterior K-wire can be placed pointing to the base of the coracoid. This allows for better fixation of the tracker. The tracker unit is then placed and fixed on the K-wires. The camera should be adjusted such that it





**Fig 8.** (A) Right shoulder, beach-chair position. The glenoid reaming is performed after checking the correct inclination and retroversion. (B) The navigated augmented reality system gives the surgeon the planned (PL) and real-time (RT) depth, inclination and retroversion values. On the right side of the image, 2-dimensional computed tomography scan images show the PL (green) and RT (blue) baseplate position in the axial (superior) and coronal (inferior) planes. (G, glenoid; R, reamer.)

faces the receiver unit of the different instrumentation (Fig 5, Video 1).

### Augmented Reality System

The navigated AR system shows the scapular registration in 2 stages and the different instrumentation of the glenoid placement in 6 stages. Each stage is visualized consecutively. The HMD will show the surgeon important information during each stage of the procedure.

### Scapular Registration

Scapular registration is performed using the navigated pointer. The first stage consists of marking four points on the posterior, superior, anterior, and inferior borders of the glenoid. (Fig 6, Video 1). The second stage is to mark 30 unique points around the glenoid surface (15 points) and the coracoid (15 points) (Fig 6, Video 1). It

is important to note that the plan is derived from a CT scan, meaning that only bony anatomy is segmented. If there is remaining cartilage on the glenoid surface, the cartilage must be penetrated until the bone surface is reached.

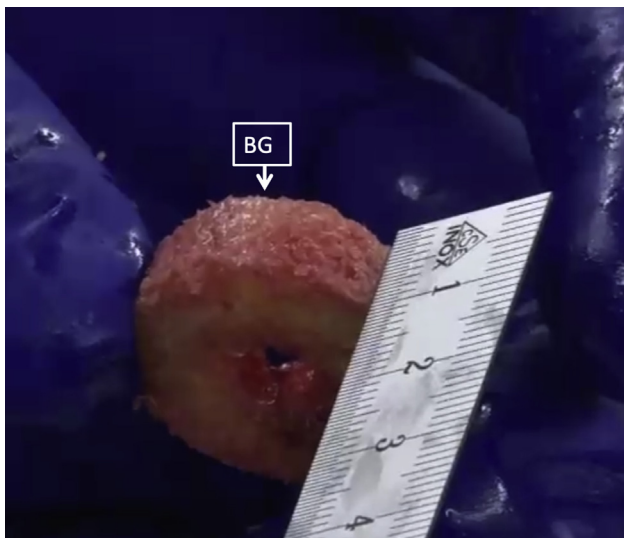
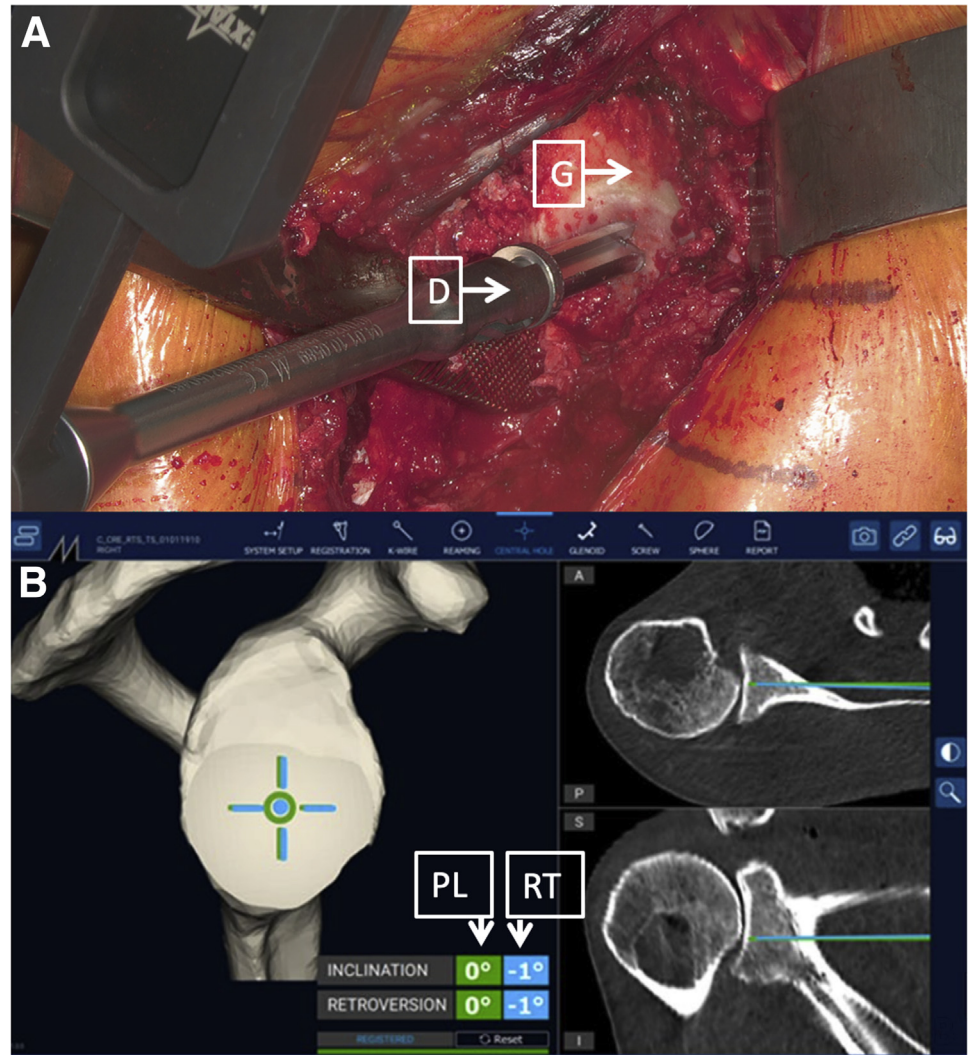
### Glenoid K-Wire Placement

The glenoid K-wire is placed using the guide. The navigated AR system gives the surgeon the planned and real-time insertion points, alignment, inclination, and version values (Fig 7, Video 1). Once the desired position is achieved, a central 2.5-mm K-wire is inserted.

### Glenoid Reaming

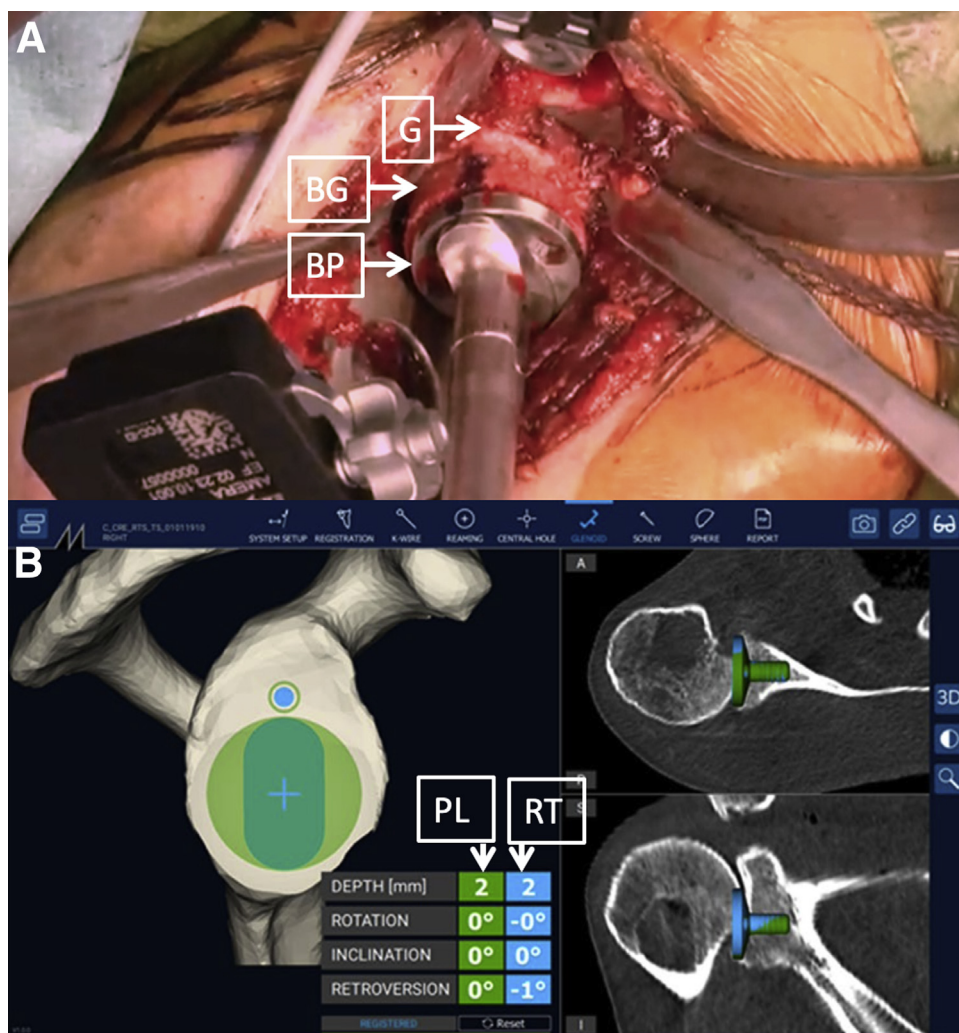
Glenoid reaming is performed after checking the correct inclination and retroversion. The navigated AR system gives the surgeon the planned and

**Fig 9.** (A) Right shoulder, beach-chair position. The glenoid central hole for the central peg of the baseplate is drilled through the K-wire. (B) The navigated augmented reality system gives the planned (PL) and real-time (RT) inclination and retroversion values. On the right side of the image, 2-dimensional CT scan images show the PL (green line) and RT (blue line) direction in the axial (superior) and coronal (inferior) planes. (D, drill; G, glenoid.)



**Fig 10.** The bone graft (BG) preparation is performed following the preoperative planning.





**Fig 11.** (A) Right shoulder, beach-chair position. The glenoid baseplate (BP) with the bone graft (BG) are impacted. (B) The navigated AR system gives the planned (PL) and real-time (RT) depth, inclination and retroversion values. On the right side of the image, 2-dimensional computed tomography scan images show the PL (green) and RT (blue) baseplate position in the axial (superior) and coronal (inferior) planes. (G, glenoid.)

real-time depth, inclination, and version values (Fig 8, Video 1).

#### Glenoid Central Hole

The glenoid central hole for the central peg of the baseplate is drilled through the K-wire. The navigated AR system gives the planned and real-time inclination and version values (Fig 9, Video 1).

#### Glenoid Baseplate Placement

Bone graft preparation is performed on the back table (Fig 10, Video 1). The graft is inserted together with the glenoid baseplate using an impactor. The navigated AR system provides the surgeon with baseplate depth, inclination and version (Fig 11, Video 1).

#### Screw Drill

With the navigated drill sleeve, the surgeon can determine the optimal direction and length of each baseplate screw (Fig 12, Video 1).

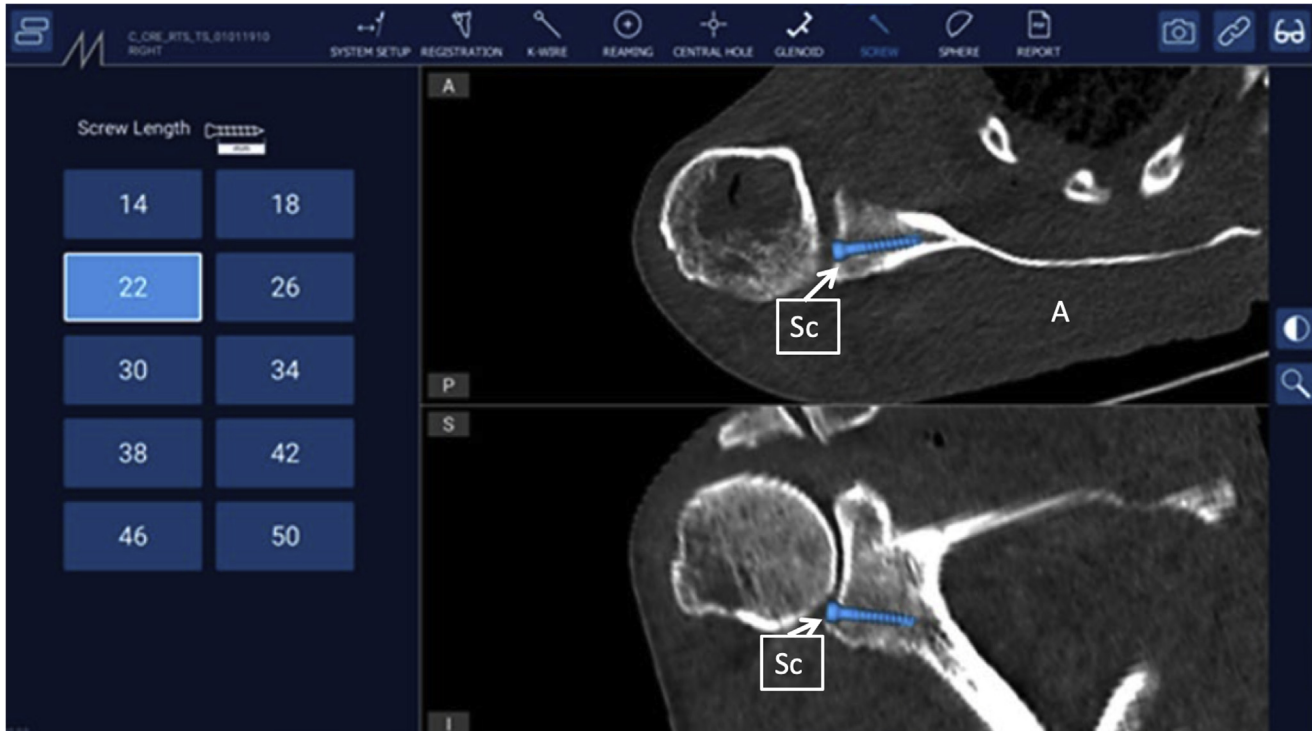
#### Glenosphere Placement

The navigated AR system gives the surgeon real-time information regarding the position and rotation of the glenosphere, enabling optimal and easier implantation (Fig 13, Video 1). A secure screw is used after the placement, followed by the glenosphere impaction.

#### Humeral Component Placement

Standard humeral component implantation is then performed. The humeral protector and the broach are extracted, and the trial humeral





**Fig 12.** The drill for the screws is made using navigated augmented reality (AR) system. The navigated AR system shows the direction and length of each screw (Sc) inside the bone. On the right side of the image, 2-dimensional computed tomography scan images show the screw position in an axial (superior) and coronal (inferior) planes.

diaphysis is placed. The metaphysis is reamed through a guide on the humeral trial. The definitive implant is then impacted, the chosen liner is inserted, and the implant is reduced. Finally, the subscapularis is reattached via multiple transosseous sutures.

The advantages and disadvantages of this technique are described in [Table 1](#). The tips and pitfalls of this technique are presented in [Table 2](#).

### Postoperative Rehabilitation

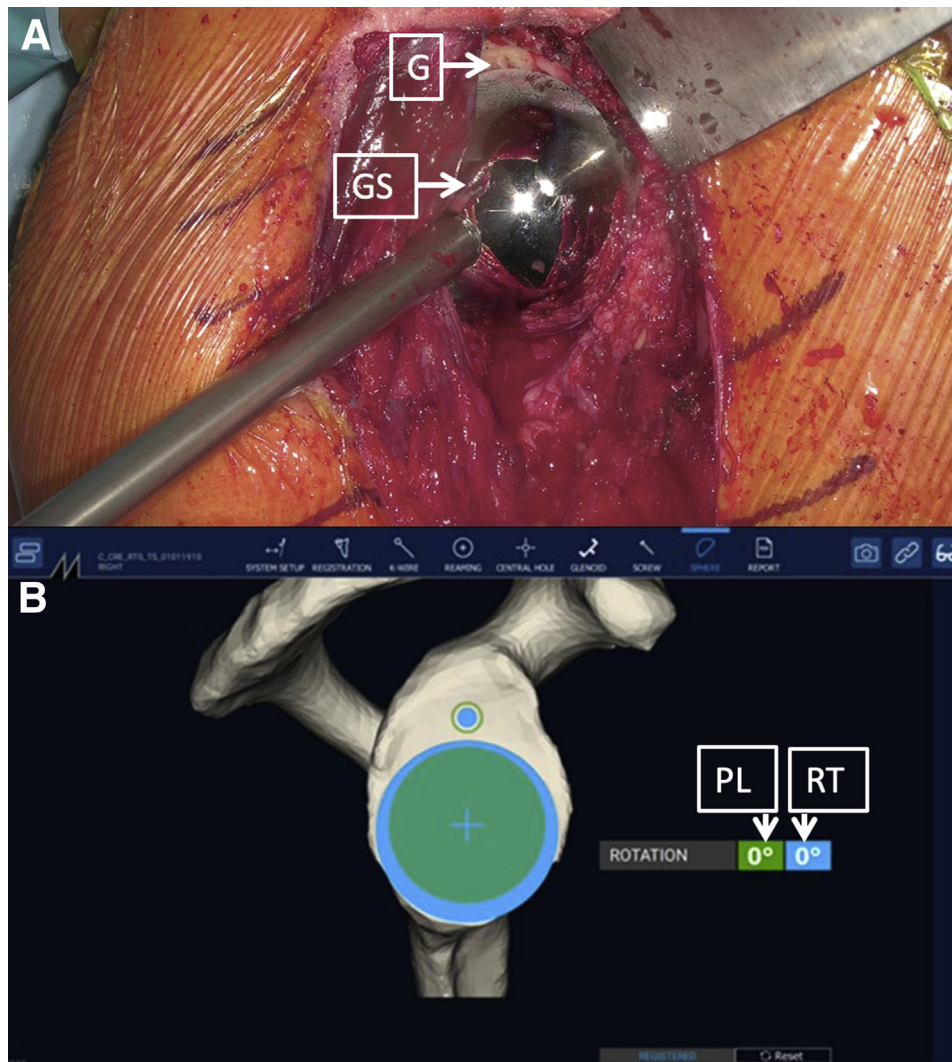
The patient is placed in a sling for 6 weeks. Passive range of motion is begun immediately. Active and active-assisted range of motion is allowed 3 weeks after surgery. A standard postoperative rehabilitation protocol for RSA with progression to early strengthening and full strengthening exercises is prescribed. The first follow-up with standard radiographs is performed 6 weeks postoperatively ([Fig 14](#), [Video 1](#)).

### Discussion

This article describes glenoid component placement using a navigated AR system through HMD. The

navigated AR system allows for a seamless transfer of the preoperative plan into surgical procedure. Intraoperative navigation allows for accurate glenoid placement, specifically when it is correlated in real-time with patient images.<sup>11</sup> Sprowls et al.<sup>19</sup> evaluated a computational navigation system combined with patients' preoperative images in real time. The authors confirmed that a better placement of base-plate screws was achieved. Their specific navigation system has similarities with the one used in this study; however, the information was not visualized through an HMD. Usage of the HMD allows the surgeon to maintain focus on the surgical field. The use of HMD has been described in various medical fields including orthopaedics.<sup>20</sup> There is limited literature regarding the usage of HMD in RSA. Gregory et al.<sup>10</sup> published their experience with one in vivo patient using a HMD with mixed reality technology. In this study, patient information was available during the procedure, but the system did not allow for real-time feedback on component placement.

The use of navigated AR system through HMD in shoulder arthroplasty has recently been published in an



**Fig 13.** (A) Right shoulder, beach-chair position. Finally, the glenosphere (GS) is put in place, impacted and secured. (B) The navigated augmented reality system gives planned (PL) and precise real-time (RT) information regarding the position and rotation of the GS. (G, glenoid.)

in vitro setting.<sup>15-17</sup> Kriechling et al.<sup>15</sup> described a feasibility study of a navigated AR system through HMD in 3D-printed scapula models showing a mean deviation of 2.3 mm and 2.7°. Recently, the same group evaluated the same system in cadavers reporting 3.5 mm and 3.8° deviation.<sup>17</sup> The authors used navigation only for K-wire placement, without information regarding depth, rotation, glenoid placement, or screw position and length. These findings suggest that the usage of navigated AR systems through HMD for shoulder arthroplasty is promising. Navigated AR systems allow accurate placement of the screws. In this circumstance, alternative modalities such as PSI are not feasible.

## Conclusions

Using a navigated augmented reality system through a head-mounted display for placement of the glenoid component in RSA is viable in an in vivo setting.

**Table 1.** Advantages and Disadvantages

### Advantages

- Real-time information of glenoid component placement according to planning.
- Information through head-mounted display allows the surgeons to stay focused on the patient.
- Easy to position trackers and calibration of the navigated augmented reality system.

### Disadvantages

- Dispensable sensors for the tracking system add extra cost.
- Theoretical risk of coracoid fracture when placing the tracker.



**Table 2.** Pearls and Pitfalls**Pearls**

Careful planification by the surgeon and explanation to the rest of the surgical team allows a more fluent surgery.

Meticulous release of the posterior and anterior glenohumeral capsule is essential to have a complete glenoid exposure.

To have a better fixation of the tracker, the K-wire for the tracker holder must be directed to the base on the coracoid, especially in small coracoids.

Pin placement for tracker holder on the coracoid with precaution of not going too medial or too deep. Control by touching the inferior border of the coracoid.

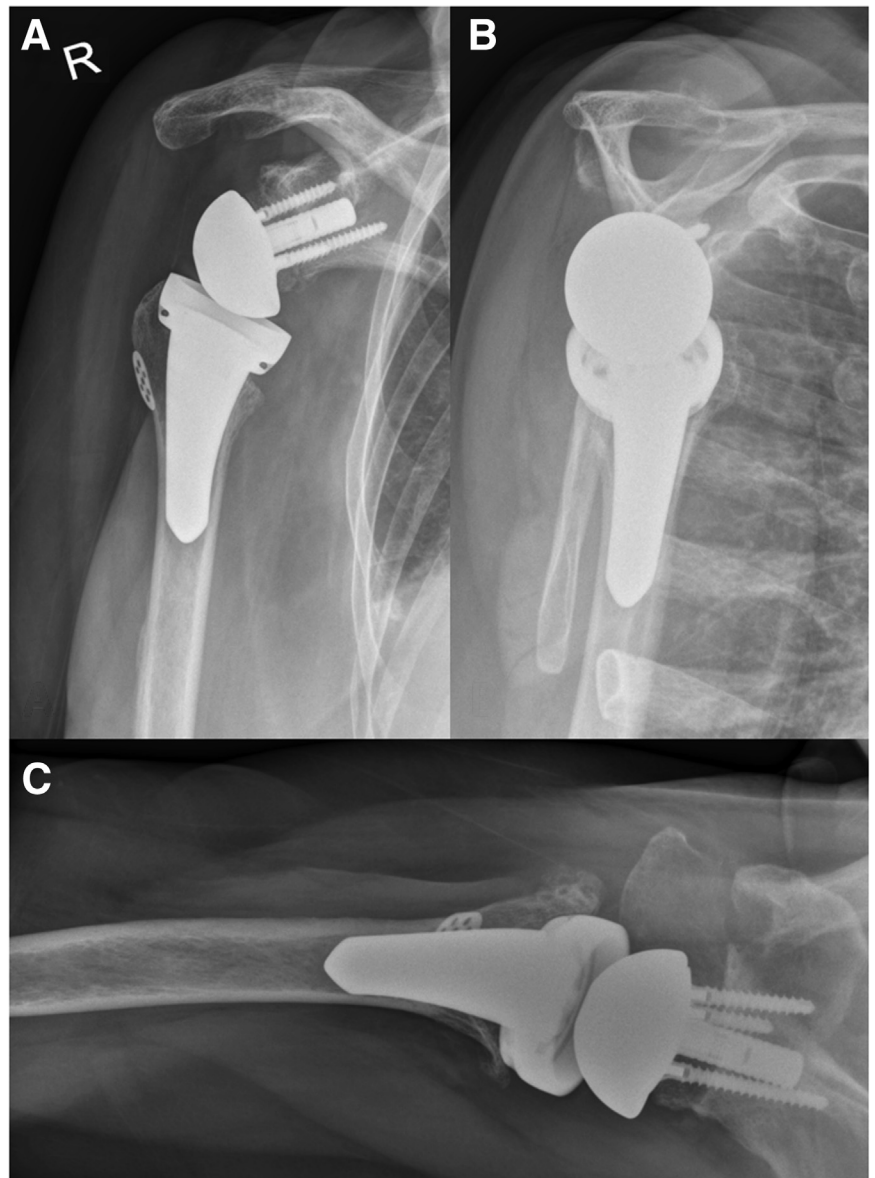
Place tracker should be calibrated aligned to the camera.

If a graft is planned for lateralizing the glenoid, a long peg baseplate (25 mm) should be used.

**Pitfalls**

A loose placement of tracker will give wrong information regarding instrument position.

A lack of soft-tissue release will hinder the procedure on the glenoid.



**Fig 14.** (A) Postoperative anteroposterior view, (B) Neer view, and (C) axillar view of the right shoulder shows a proper placement of the glenoid component according to the preoperative planning.

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