An Analysis of Planned Inclination Correction by Reaming in Reverse Total Shoulder Arthroplasty

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Background: The optimal inclination of the glenoid component in reverse total shoulder arthroplasty (RSA) is debated; however, an inferiorly tilted or neutral glenoid baseplate typically requires corrective reaming, structural grafting, or an augmented baseplate. Significant corrective reaming of the inferior glenoid has been theorized to result in medialization, a shortened scapular neck, and impingement. Few reports have described the relationship between the amount of reaming and factors such as degrees of inclination correction, indication for RSA, and patient demographics.

Purpose: To characterize these effects in a large series of RSA cases that were 3D planned with pre-operative planning software.

Methods: A retrospective review of RSA cases planned by a single surgeon using a commercially available 3D CT software planning program between 2018 and 2020 was conducted to evaluate the relationship between the 3D virtual reaming depth (mm) required to execute the planned 3D glenoid inclination change along with RSA indication and patient factors. Cases planned for reconstruction using structural graft (defined as planned backside seating <75%), those using an augmented glenoid baseplate, and cases with planned glenoid inclination greater than native glenoid inclination were excluded. Pearson's correlation coefficient was calculated to evaluate the relationship between the planned reaming depth and the above factors.

Results: Sixty-three cases met the inclusion criteria in 29 males (46%) and 34 females (54%). The indications for planning of RSA included 22 cases of rotator cuff arthropathy (35%), 26 cases of massive rotator cuff tears or fracture with no osteoarthritis (41%), and 15 cases of cuff-intact osteoarthritis (24%). The median native 3D inclination was 9 degrees (IQR=6-13). Seventy percent of cases were planned to have a final implant inclination of 0 degrees. The median amount of inferior glenoid reamed was 8 mm (IQR=6-10). Corrective reaming depth was strongly, positively correlated with planned degrees of inclination correction, r (61) =0.67, p<0.001. No significant correlation was found between reaming depth and RSA indication or any patient factor such as age or sex.

Conclusions: Corrective reaming depth of the inferior glenoid in 3D planned RSA cases is highly correlated with correction of superior glenoid inclination. Each 1-degree correction in inclination requires approximately 0.9 mm of inferior reaming. An average reaming depth of 8 mm in the current series was necessary to achieve an average 9-degree inclination correction to neutral tilt.

What this study adds: This study quantifies the relationship and direct correlation between the degree of superior glenoid inclination correction and the depth of inferior reaming required in reverse shoulder arthroplasty.

How this study might affect research, practice or policy: These findings provide surgeons with practical guidance for preoperative planning that may help optimize implant positioning, reduce unnecessary bone removal, and guide future research on implant design and surgical decision-making.

Study Design: Basic Science Study; Computer Modeling

Level of Evidence: Level IV

Keywords: reverse shoulder arthroplasty; three-dimensional planning; CT scan; glenoid inclination; glenoid corrective reaming

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Introduction

Glenoid baseplate placement is a key step in reverse total shoulder arthroplasty (RSA) and in the current era this often begins with three-dimensional (3D) computer-assisted planning. With expanding indications for RSA, a wider variety of pathology is being addressed often with increasing complexity and deformity [1][2][3][4][5]. While RSA has good overall long-term survival rates, accurate placement of the glenoid component is critical to avoiding potential complications. This often presents a significant challenge in cases with glenoid bone loss and deformity, highlighting the benefit of preoperative planning [6]. Numerous studies have investigated the utilization of three-dimensional (3D) virtual planning to improve the precision of component positioning [4][6][7][8].

The use of 3D preoperative planning software to simulate glenoid component implantation allows for a more thorough evaluation of the pathologic anatomy, better understanding of deformities requiring correction, and proper prosthesis positioning and sizing. Implementation of 3D preoperative templating also results in more reliable measurement of glenoid version and inclination with improved accuracy in placement of the glenoid component compared to standard techniques in RSA [9][10][11]. 3D preoperative planning is particularly beneficial in patients with glenoid deformity and bone loss, and it can be very helpful with intraoperative decision-making. However, it is not without limitations, as there is a spectrum of technical variations among the numerous commercially available systems [12]. Still, the role of 3D preoperative virtual planning in RSA remains a key research focus given the potential to improve component implant accuracy and presumably, improve overall patient outcomes.

Glenoid malposition can lead to numerus reported complications. Optimal inclination of the implant is critical to attaining the best result. Superior tilt of the baseplate has been shown to lead to impingement, increased polyethylene wear, scapular notching, instability, and glenoid loosening [7][13][14][15][16]. Although there is still some debate, inferior placement on the glenoid and an inclination angle ≤ 0º are generally accepted guidelines for baseplate positioning in RSA **(Figure 1)** [5][14]. From a technical standpoint this can be accomplished by reaming, baseplate augmentation (either with bone or metal), or a custom implant. Flat (non-augmented) baseplates often require eccentric inferior glenoid reaming to achieve this [4][5][14]. The amount of inferior glenoid reaming required to achieve neutral baseplate tilt with full backside seating is poorly described. Similarly, the correlation between the amount of inferior reaming required to correct a certain degree of glenoid inclination remains unknown.

Therefore, the purpose of our study was to investigate the amount of 3D-planned inferior reaming in a series of RSAs and determine whether the planned reaming required to fully seat the baseplate is influenced by planned change in inclination, age, sex, or surgical indication. The hypothesis of this study was that there would be a positive correlation between the amount of inferior glenoid bone reamed and planned change in inclination. We also believed there would be a difference in the amount of planned reaming based on patient factors such as indication for RSA, age, and sex.

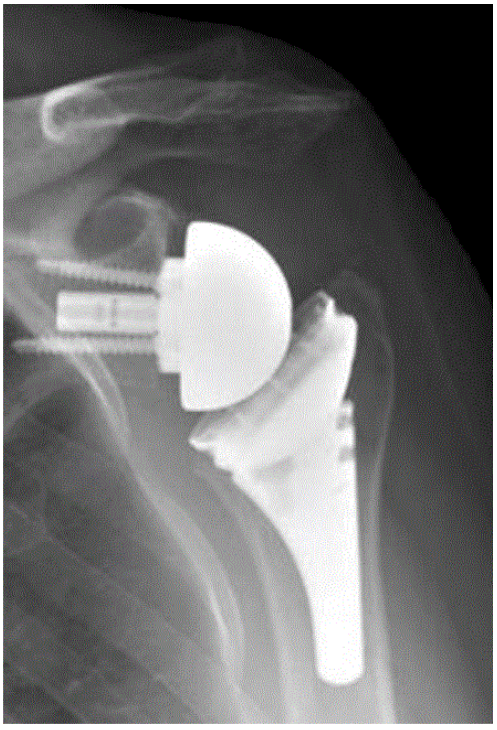


Figure 1. True anterior-posterior (Grashey view) radiograph demonstrating a reverse total shoulder arthroplasty with a non-augmented standard baseplate positioned inferior on the glenoid face with neutral tilt and full-backside contact.

Table 1. Patient eligibility, demographics, indication for RSA, and glenoid measurements

Eligibility	
Included	63 patients
Excluded	24 patients
Demographics	
Age (years)	73 (range, 47-94)
Male	29 (46%)
Right Shoulder	36 (57%)
Indication for rTSA	
Massive rotator cuff tear or fracture (no osteoarthritis)	26 (41%)
Rotator cuff arthropathy	22 (35%)
Cuff-intact osteoarthritis	15 (24%)
Glenoid Measurements	Median (IQR)
Native 3D inclination	9 degrees (IQR 6-13)
Surgeon planned 3D inclination	0 degrees (IQR 0-0)
Planned change in inclination angle	9 degrees (IQR 6-12)
Planned inferior glenoid depth	8 mm (IQR 6-10)

Materials and Methods

A retrospective review was performed of a database containing RSA cases of a single surgeon in which a commercially available 3D computed tomography (CT) software program was used to plan surgical implantation of the glenoid component. A standard non-augmented baseplate was used. The database was queried from May 2021 through June 2021 and contained cases planned from 2018 through 2020. A total of 87 patients plans were screened, of whom 63 were included and 24 were excluded. Exclusion criteria were reconstruction with a structural graft due to <75% backside seating with a standard baseplate, use of an augmented wedged baseplate, or planned glenoid inclination correction greater than the native inclination. The final study population consisted of 29 males and 34 females **(See Table 1 for further detail)**.

For this 3D planning software, a CT scan is submitted and processed by a trained technician. CT processing includes the creation of a 3D virtual model of the scapula and measurements of the 3D native glenoid inclination and version angle in degrees (º) using anatomic landmarks. Additionally, a preliminary surgical plan is generated that must meet FDA guidelines for implant inclination and version (maintaining version between -10º and 10º, inclination between -10º and 0º) while also striving to meet certain technical goals that are considered reliable rules of thumb for placement of a non-augmented baseplate for RSA. These goals include matching the size of the baseplate with the native glenoid, avoiding medialization >5 mm, minimizing central vault perforation and having rotation match the native glenoid **(Figures 2 and 3)** [9].

The surgeon then finalizes and approves the surgical plan. During this period of the senior surgeon's practice, the goal of the final construct was to have the inferior aspect of the sphere at or below the inferior glenoid, not the baseplate **(Figure 4)**. A lateralized sphere was used with a 135º neck-shaft angle. After finalization, there are several parameters recorded by the software including implant type, implant size, planned implant version, planned implant inclination, and implant backside seating reported as a percentage of the backside of the implant that is in direct contact with the glenoid surface. The 3D native glenoid inclination angle and finalized planned glenoid inclination angle was extracted from the software planning database. Patients' age, sex, and indication for RSA were recorded from their electronic medical record and analyzed to determine influence on initial glenoid inclination and therefore required correction and reaming. Cases planned for reconstruction using a structural graft (planned when backside seating <75%), those using augmented baseplates, and cases planned with corrected glenoid inclination greater than native glenoid inclination were excluded **(Figure 5)**.

The 3D virtual reaming depth (mm) required to achieve the planned inclination correction was measured using the 3D planning software measurement tool. Measurements were performed on the coronal cut of a 2D CT scan at the mid-glenoid slice. Two points were marked to define the distance measured; one at the most lateral point of the inferior glenoid bone (native, osteophyte, calcified labrum), and the other at the point of perpendicular intersection between the medial surface of the planned glenoid baseplate. A virtual line was drawn through the identified points and the projected reaming distance was calculated **(Figure 4)**.

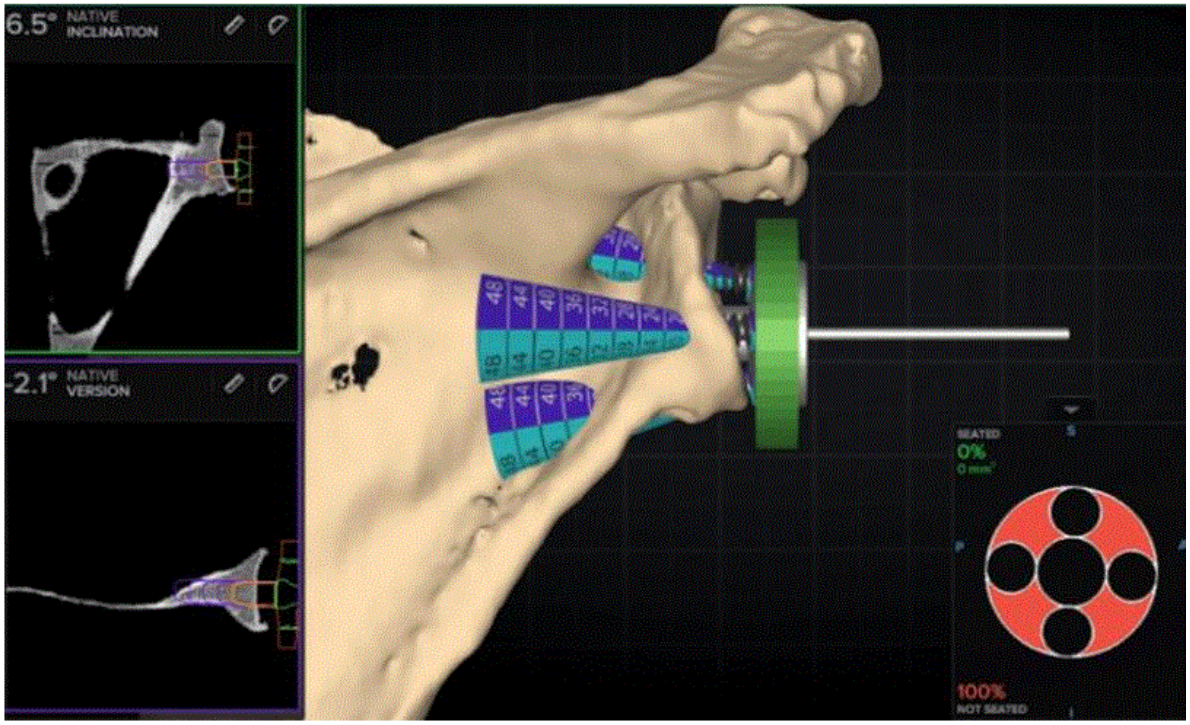


Figure 2. RSA planning using 3D software showing a glenoid with native superior inclination of 6.5°. The RSA baseplate initial position demonstrates 0% seating with the baseplate in neutral tilt.

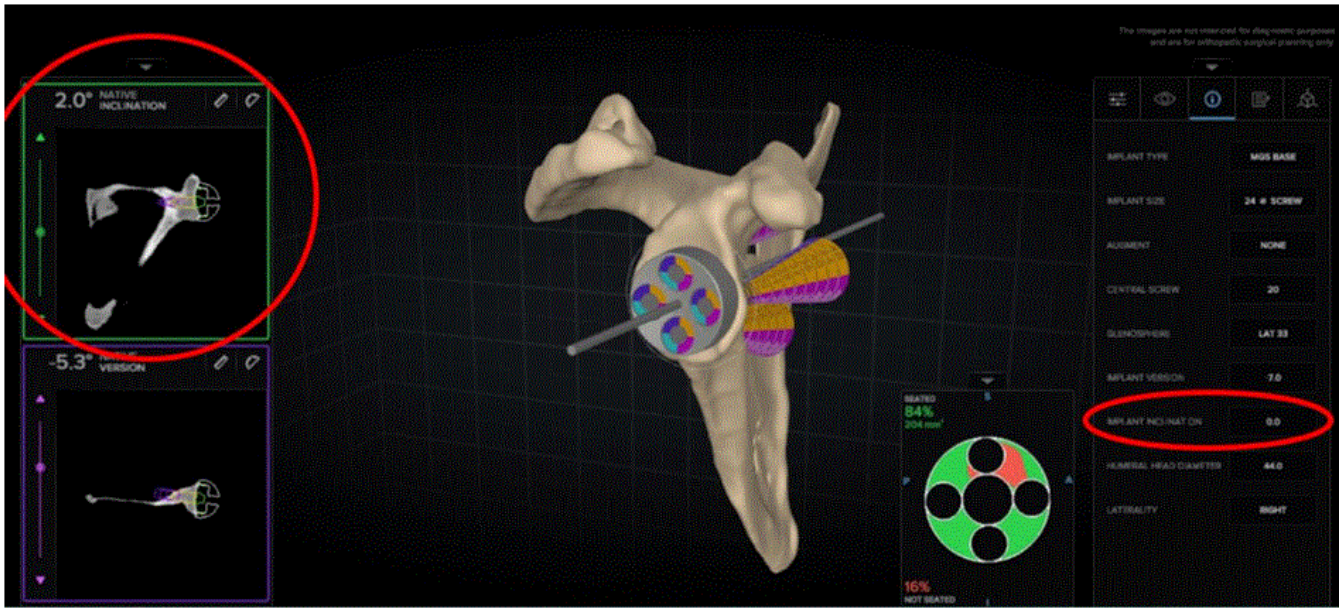


Figure 3. Demonstrating a screenshot of the planning software highlighting the implant positioned in 0 degrees of inclination with reaming to correct 2.0 degrees of native inclination. Circled portion top left highlights position of the sphere at inferior portion of the glenoid.

Statistical Methods

The primary outcome variable in this study was planned depth of inferior bone reamed (mm). The predictor variables were patients' native inclination (degrees) measured by the 3D planning software technician, the surgeon planned final RSA inclination (degrees), age, sex, and surgical indication. We fitted a generalized linear model to determine whether glenoid reaming depth could be predicted from the change in planned inclination, age, sex, and surgical indication. The Pearson's correlation coefficient was then calculated to evaluate the relationship between the planned reaming depth and the above factors. Statistical significance was set at $P < .05$.

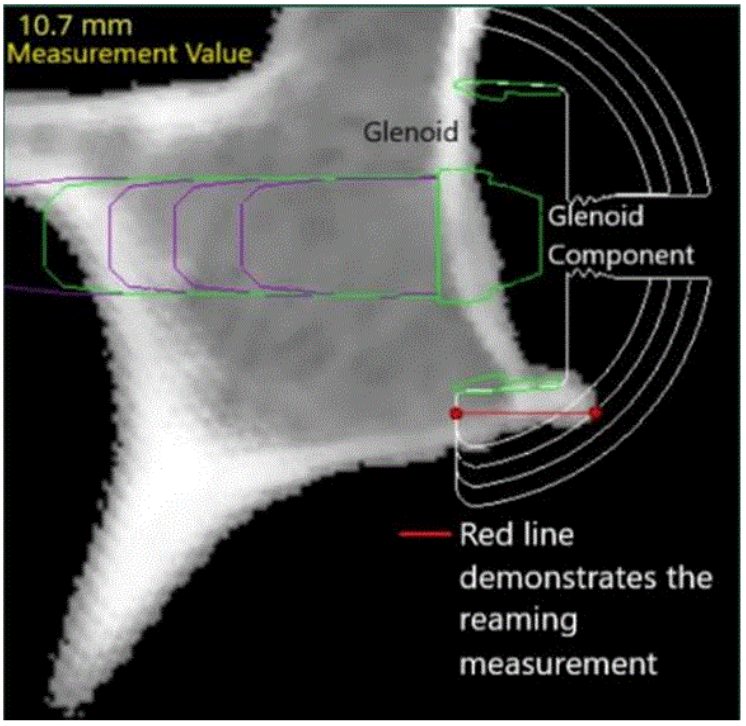


Figure 4. Screenshot demonstrating output provided by VIP 3D planning software. Red line demonstrates the method for calculating the depth of reaming. Baseplate templating highlighted in green with the baseplate planned for neutral tilt. Glenosphere component position was planned to be at the inferior margin ensuring that the inferior aspect of the glenoid was covered.



Figure 5. Example of case with native inclination of -14.5 degrees (or inferior tilt). In this case native inclination was less than planned inclination so this case was excluded.

Results

During the two-year period analyzed, 87 reverse total shoulder arthroplasty cases were entered into the pre-operative planning software. A total of 63 patients met the inclusion criteria. The mean patient age was 73 years old (range, 47-94 years). Twenty-nine of the patients were male (29/63, 46%), and the right shoulder was the operative shoulder in 57% of the cases (36/63) **(Table 1)**.

The indication for RSA varied amongst the cohort. Massive rotator cuff tears or fracture cases (patients with no

osteoarthritis) accounted for 26 patients representing 41% of the cohort. Twenty-two patients had rotator cuff arthropathy (35%), and 15 patients were indicated for cuff-intact glenohumeral osteoarthritis (24%).

Most patients presented with positive native glenoid inclination. The median superior inclination was 9 degrees (IQR 6-13). The vast majority of patients were planned to correct glenoid tilt back to neutral or 0 degrees of inclination **(Figure 6)**. The median planned change in inclination was 9 degrees (IQR 6-12) and the planned depth of inferior glenoid reaming was 8 mm (IQR 6-10).

The generalized linear model revealed that the planned inclination correction angle was the only significant predictor of reaming depth. Therefore, we decided to plot the correlation between the planned correction of inclination and millimeters of glenoid reaming needed to achieve that correction. The Pearson correlation coefficient was 0.67 **(Figure 7)**. For every 1 degree of inclination corrected, roughly 0.9 mm of inferior glenoid reaming was required. Planned reaming was poorly predicted by surgical indication, age, or sex.

Discussion

This study highlights several clinically relevant findings including the strong positive correlation between planned change in inclination and required inferior glenoid reaming. The main finding of this study is that for every 1 degree of superior inclination correction, it requires nearly 0.9 mm of inferior glenoid reaming. Understanding the amount of eccentric reaming necessary to correct superior glenoid tilt is critical and affects surgeon decision making when planning and performing RSA. Care must be taken when performing RSA to avoid removing too much bone from the inferior glenoid as it could compromise the subchondral plate and make it difficult to achieve stable baseplate fixation [5][6][17][18]. At the same time, implanting the baseplate with appropriate tilt correction is crucial to optimizing results.

Boileau et al. emphasized the importance of surgeons recognizing and correcting glenoid superior inclination at the inferior portion of the glenoid where the RSA baseplate is positioned [17]. Placing the implant in neutral inclination has been shown to maximize the efficiency of the rotator cuff muscles [17][19][20][21][22]. Eccentric inferior reaming is one commonly used technique to correct inclination. In that same paper, Boileau et al. describe 3 surgical alternatives, these include metallic augmented baseplates, glenoid bony augmentation with an inferiorly inclined bone grafting (BIO-RSA), and use of custom patient specific baseplates [5][14][17]. With the use of structural and metal augments, biplanar glenoid deformity (retroversion and inclination) can be corrected with little inferior glenoid reaming [14][23][24][25][26].

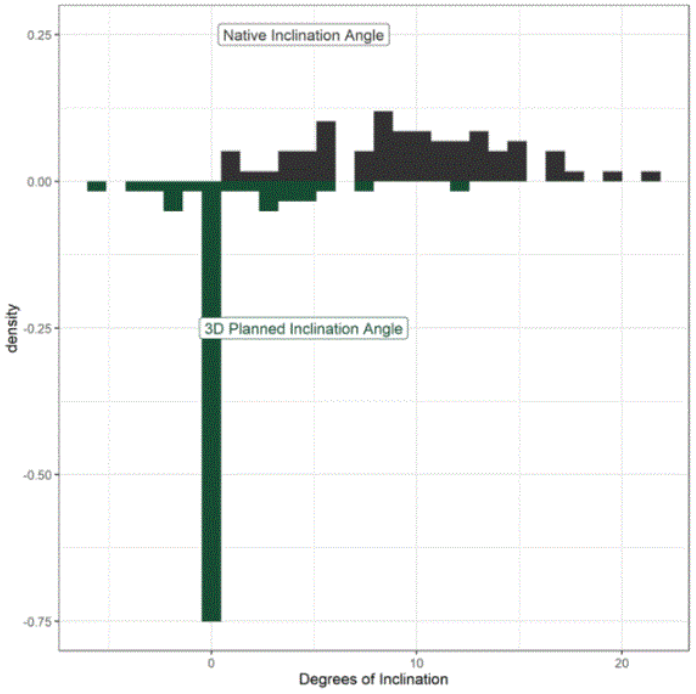


Figure 6. Overlaid density histogram comparing native glenoid inclination (black) and 3D planned inclination (green). The graph demonstrates a consistent correction toward neutral inclination.

When planning and positioning the baseplate in RSA, various trade-offs must be considered by the surgeon. Eccentric reaming necessitates greater inferior glenoid exposure and capsular releases, resulting in increased overall medialization. In contrast, augmented components may reduce the need for as much inferior dissection and potentially lower the theoretical risk to the axillary nerve, be less technically demanding, decrease the amount of operative time, and avoid the risk of graft failure [24][6]. However, custom and metal augmented baseplates have a higher cost burden, may not be universally available, and if not carefully executed can lead to excessive implant lateralization.

We found no significant difference in reaming depth regarding indication for reverse total shoulder or patient sex. These findings were slightly unexpected. Previous studies have investigated the difference in glenoid inclination between patients with osteoarthritis and those with cuff tear arthropathy and massive rotator cuff tears [26]. Using 3D software, Daggett et al. showed that on both AP radiographs and 3D CT software that patients with massive rotator cuff

tears had significantly increased glenoid inclination in comparison to shoulders with osteoarthritis. They found that the massive rotator cuff tear group had a mean glenoid inclination of 13.6 degrees compared to the osteoarthritic group which was from 4 to 4.5 degrees [23]. This intuitively would lead one to believe that patients with cuff tear arthropathy would require more inferior reaming with a flat baseplate to correct back to neutral tilt. Although this may not be able to be strictly inferred as patients indicated for surgery secondary to osteoarthritis may have more pre-existing glenoid osteophytes that would require reaming or removal to enable baseplate seating.

There are differing methods on how to perform eccentric reaming to correct inclination. In another study using 3D preoperative planning software, Dilisio et al. virtually planned 16 shoulders using both the subchondral smile technique (performed by reaming at a coronal inclination that would result in the appearance of a smile along the inferior glenoid with at least 120 degrees of reamed bone) or 10-degree inferior tilt surface guide technique to see if either method reliably produced inferior glenoid tilt relative to the transverse axis of the scapula. They found that neither method is reliable to produce sufficient inferior glenoid tilt. With the subchondral smile technique, the baseplate remained implanted in a mean of 8.9º superior tilt, while the 10-degree surface guide technique the baseplate was implanted in 2.8º of tilt [7]. This highlights the importance of adequately reaming as both techniques on average would require additional reaming and medialization to achieve full correction to neutral.

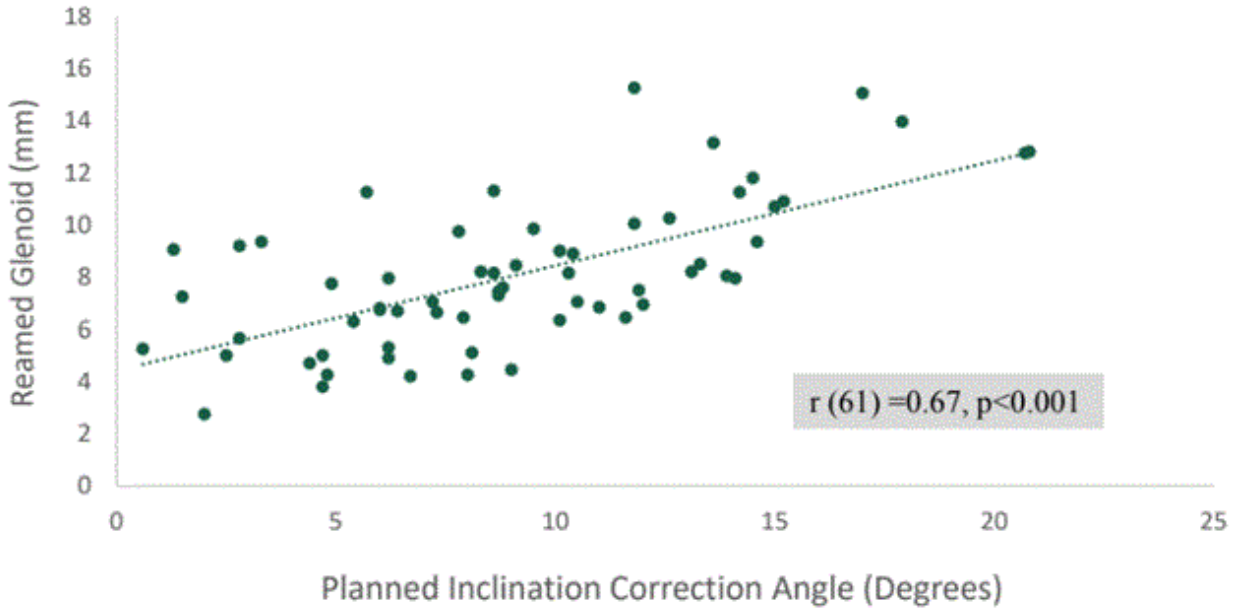


Figure 7. Planned inclination correction (degrees) demonstrates a linear relationship with the amount of inferior glenoid reamed (mm). (r (61) = 0.67, p<0.001)

In this series, all corrective reaming could have been avoided by utilizing either the 10º or 20º full wedge augmented component. Several studies have supported the use of augmented metallic baseplates to manage glenoid deficiency in RSA [23][25][27][28][29][30][31]. Colasanti et al. compared 540 primary RSA with superior augments vs 47 patients with bone grafting and found the augment group demonstrated significantly quicker operative times, 3x less scapular notching, and 8x fewer adverse events requiring revision with higher patient reported outcome measures [27]. In a recent multicenter retrospective analysis of 145 patients who underwent RSA with intraoperative navigation and had 3-year follow up, Levin et al. found superior augmentation even in patients without significant glenoid deformity (defined as <10º of superior inclination and <15º retroversion) achieved greater planned inclination correction (6.4º vs 1.3º, P<0.001) and a lower proportion of glenoid components planned to have superior tilt (1.9º vs 14.3º, P<0.001). The augmented group also trended toward shorter operative times, improved postoperative patient-reported outcomes, similar ROM and adverse events compared with standard baseplates [25]. Metallic augmentation also avoids concerns for graft resorption and other complications with bone graft augmentation (BIO-RSA). Merolla et al. compared bone graft augmentation (BIO-RSA) with metallic baseplate augmentation and found that both provided good clinical outcomes; however, final graft union with the native glenoid was <70% in the BIO-RSA group compared with complete baseplate seating of 90% of the augmented baseplate group [32].

Patel et al. further investigated the effect of inferior tilt of the glenoid component in reverse shoulder arthroplasty. They found that an inferior tilt of −10º compared to 0º tilt resulted in increased medialization necessary to fully seat the implant, which shortened the scapular neck and increased the risk of scapular notching and impingement-related instability. In their simulated study the average length of scapular neck reamed was 6.3 mm and 9.5 mm (0º tilt vs −10º of tilt) depending on the inclination of the glenoid component. [4] This represented 119% and 179% of the relative scapular length removed in each group, and a high proportion in their simulation were left with no scapular neck remaining. These values are comparable to what we found where the median amount of scapular neck reamed was 8 mm, although we planned our baseplate to be in 0º tilt. The length of the scapular neck should be considered when determining the appropriate technique for correcting superior inclination.

In another computer simulated study looking at anterior corrective reaming for retroversion correction in biconcave retroverted glenoids, Aleem et al. found that on average to correct to 15º of retroversion it required 5 ± 3 mm or reaming, and correction to 10º required 8 ± 3 mm of reaming. 33 In more severely retroverted glenoids, the amount of reaming approached and even exceeded 10 mm. While this study specifically focused on anatomic total shoulder arthroplasty, the relationship between glenoid bone reamed and version correction can also be applied to reverse shoulder arthroplasty. They found a similar linear relationship that for every degree of increased retroversion correction, an additional 0.3 mm of anterior reaming was necessary to achieve at least 80% seating of the glenoid component. This is less than the 0.9 mm per degree of inclination correction that we found but also could differ slightly because of the differing goals in backside seating in the two studies.

When they looked at revision surgery for reverse total shoulder arthroplasty, Boileau et al. found that the most common cause for RSA revision was prosthetic instability (48%). They found that two major factors led to recurrent instability in their series, underestimating the humeral shortening and excessive glenoid medialization [1]. Understanding the amount of inferior glenoid reaming in the primary index procedure is one way to potentially avoid the risk of excessive glenoid medialization. Glenoid bone loss, the use of too small of a glenosphere, or excessive glenoid reaming can lead to this medialization and make it difficult to restore proper deltoid tension. 1,6 Rojas et al. retrospectively studied the effect of medialization on 91 patients who underwent primary RSA with eccentric reaming and found that those with increased medialization had decreased postoperative external rotation, but no worse outcomes or increased rates of loosening at short term follow-up [34].

There are several limitations to our study. The study is based on the calculated measurement of reaming depth made on pre-operative CT scans. This is heavily influenced by the desired position of the glenoid component. The planned final implant was positioned so that the inferior overhang of the glenosphere was positioned at or slightly below the inferior margin of the glenoid in all cases **(Figure 4)**. The position of the implant from the inferior margin of the glenoid and the degree of glenoid inclination are important variables that determine the amount of reaming necessary to ensure full backside contact of the baseplate on native bone. The calculated amount of glenoid bone reamed could have also been confounded if a portion of the most lateral aspect of the bone inferiorly represented osteophyte or calcified labrum instead of true native glenoid bone. Therefore, the depth and subsequent calculated amount of reamed bone would be overestimated. Another limitation of the study is that it included no imaging follow-up as part of the study protocol to see if the proposed plan was executed. It also did not include any correlation with clinical survivorship or patient outcomes. Further studies are needed in this area. Lastly, the software we used only allowed for planning with that manufactures implants and no comparison was made between implants of various design.

Conclusion

The corrective reaming depth of the inferior glenoid in 3D planned RSA cases is highly correlated with the amount of superior glenoid inclination correction. When planning for a non-augmented baseplate in neutral inclination with full backside seating it required on average 9 degrees of inclination correction which resulted in a median reaming depth of 8 mm. For every 1 degree of inclination correction nearly 1 mm of inferior reaming is required.

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Conflict of interest

Robert U. Hartzler reports publishing royalties from Wolters Kluwer Health and is a paid consultant for Stryker.

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