The influence of scapular neck length on range of impingement-free adduction in reverse total shoulder arthroplasty

Running title: Scapular neck length and impingement-free adduction

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Influence of scapular neck length on the extent of impingement-free adduction after reverse total shoulder arthroplasty

Abstract

Background: Following reverse total shoulder arthroplasty, a short scapular neck length (SNL) decreases postoperative impingement-free adduction, and impingement between the neck of the scapula and the humeral polyethylene cup may cause scapular notching. However, there are no reports that have evaluated the influence of SNL on impingement-free adduction. The purposes of this study were to evaluate the influence of SNL on impingement-free adduction and to examine the effect of glenoid component lateralization and inferiorization on impingement-free adduction.

Methods: Using 3D-templating software, a virtual reverse total shoulder arthroplasty model was created in 15 patients who had no osteoarthritic change or any other bony deformity. We measured SNL separately before implant placement (preoperative SNL) and after implant placement (postoperative SNL). The implant used was the Comprehensive Reverse Shoulder system (Zimmer Biomet, Warsaw, IN, USA), and baseplate bony lateralization of 0 mm, 5 mm, and 10 mm, with inferior eccentricity of 0.5 mm or 4.5 mm were tested for impingement-free adduction. Correlations between the preoperative and postoperative SNLs and impingement-free adduction were analyzed.

Results: The mean preoperative SNL was 8.2 mm ± 1.9 mm (range, 5.0 mm to 11.7 mm), and postoperative SNL was 6.0 mm ± 2.0 mm (range, 2.1 mm to 9.8 mm). There was a moderate correlation between preoperative SNL and impingement-free adduction (r = 0.628, p = 0.12), and a strong correlation between postoperative SNL and impingement-free adduction (r = 0.771, p =

0.001). The use of the 10-mm bony lateralization and 4.5 mm of inferior eccentricity model provided the best results in impingement-free adduction.

Conclusion: There were correlations between both the preoperative and postoperative SNLs and impingement-free adduction. Although the lateralized and inferiorized center of rotation may increase the risk of loosening of the glenoid component, this offset significantly increased impingement-free adduction.

Level of Evidence: Basic Science Study: Computer Modeling

Keywords: Reverse total shoulder arthroplasty; Adduction; Scapular neck length; Onlay design; Glenoid offset; Preoperative planning

Introduction

Reverse total shoulder arthroplasty has become a preferred treatment option in older patients with cuff tear arthropathy. In 1985, Grammont introduced the first successful reverse shoulder prosthesis.[28] The Grammont prosthesis relies on medialization and inferiorization of the glenohumeral center of rotation (COR). Medialization of the COR reduces the torque of the glenoid bone-implant interface, and inferiorization restores and even increases deltoid tension.[2] However, this medialization has been associated with scapular notching because of the mechanical impingement between the humeral cup and scapular neck when the arm is fully adducted.[2]

Scapular notching is a common radiographic finding occurring after reverse total shoulder arthroplasty, and it refers to an erosive lesion and osteolysis secondary to impingement between the inferior scapular neck and polyethylene cup.[18,22] Scapular notching has long been of interest to shoulder surgeons and has been suggested as a cause of glenoid loosening.[18] Some studies have demonstrated worse clinical outcomes associated with scapular notching.[21,27-29] To address this problem, translating the center of rotation laterally or inferiorly has been recommended.[3,7,8,20] Scapular neck length (SNL) is considered to be one factor that affects the development of scapular notching after reverse total shoulder arthroplasty.[23] However, there have been no studies that have evaluated the influence of SNL on impingement-free adduction.

Computed tomography (CT)-based computer simulation studies have been used to assess the location of impingement and impingement-free range of motion (ROM) in previous studies.[7,11,14-17, 19,24,31] Although there are several limitations with computer simulation, it is possible to measure the impingement-free ROM. If impingement-free adduction is limited, it may be a cause of postoperative scapular notching. Using computer simulation, we evaluated the influence of

SNL on impingement-free adduction and examined the effect of lateralized and inferiorized offset of the glenoid component.

We hypothesized that SNL would have a correlation with impingement-free adduction. Our secondary hypothesis was that translating the center of rotation laterally and inferiorly would further increase impingement-free adduction.

Materials and Methods

Patient selection

The Institutional Review Board of the institute approved this study. We retrospectively reviewed patients who underwent CT scans at our institution, and 15 shoulders were included in this study. Included diagnoses were rotator cuff tear and shoulder impingement syndrome. Patients with radiographically apparent osteoarthritis (Kellgren–Lawrence grade[12] ≥ 3), rheumatoid arthritis, prior fractures or dislocations of the glenohumeral joint, and history of shoulder surgery were excluded.

CT imaging analysis and virtual arthroplasty simulation

CT scans were collected from a single institution. CT scans were performed with a 0.5-mm slice thickness and included the entire scapula and humerus. All slices were saved in Digital Imaging and Communications in Medicine (DICOM) format, and imported into ZedShoulder software (Lexi, Tokyo, Japan). The software defined a glenoid reference coordinate system (Fig. 1). The origin of the system was set at the mid-point of the maximum anteroposterior glenoid width. The x-axis was set as the line connecting the mid-point of the maximum anteroposterior glenoid width and the junction of the scapular spine and the medial scapular border. The z-axis was perpendicular to the x-axis in the coronal plane. The y-axis was perpendicular to the x-axis and z-axis and passed through the mid-point of the anteroposterior glenoid width. The software defined a best-fit sphere for the glenoid surface, which were detected automatically. The glenoid coordinate system was used to assess the orientation of the glenoid. The mid-point of the maximum anteroposterior glenoid width and the center of the best-fit sphere defined the glenoid centerline, with the orientation being determined as the angle between the glenoid centerline and the x-axis. Glenoid version angle was calculated as the projected orientation angle on the x-y plane, while glenoid inclination was calculated as the projected orientation angle on the x-z plane.

For this analysis, the Comprehensive Reverse Shoulder system (Zimmer Biomet, Warsaw, IN, USA) was used. All glenoid component consisted of a 36-mm + 3-mm glenosphere (25-mm baseplate) and a 44-mm STD tray. In all cases, a baseplate was implanted so that its inferior edge was flush with the inferior edge of the glenoid, the central boss was placed in the middle of the glenoid width, and the baseplate angle was 0° of version and 0° of inclination (Fig. 2). The humeral cut was virtually performed at the anatomic neck. The humeral stem prosthesis was virtually inserted in a manner that the axis of the humerus and the axis of the stem were aligned in a parallel fashion. The humeral component was implanted in 20° of retroversion with respect to the humeral epicondyles.

The definition of the glenoid component offset for analysis was designated as follows: glenoid position 1 (Fig. 2), no bony lateralization with A-offset (0.5 mm inferior eccentricity); glenoid position 2, 5 mm of bony lateralization with A-offset; glenoid position 3, 10 mm of bony lateralization with A-offset; glenoid position 4, 0 mm of bony lateralization with E-offset (4.5 mm inferior eccentricity); glenoid position 5, 5 mm of bony lateralization with E-offset; glenoid position 6, 10 mm of bony lateralization with E-offset. Impingement was defined as bone-to-bone or implant-to-bone contact. Impingement-free adduction was measured when impingement occurred. The concave polyethylene and the convex glenosphere are hypothesized to be in complete contact and are perfectly matched during motion. Impingement-free adduction analysis for the six positions of the glenoid implant was performed in all patients.

We measured the maximum anteroposterior glenoid width, the maximum superoinferior glenoid height, glenoid version, glenoid inclination, and SNL. We measured SNLs separately before implant placement (preoperative SNL) and after implant placement (postoperative SNL).

Preoperative SNL was defined as the distance between the articular surface of the glenoid and the most lateral edge of the infraglenoid tubercle (Fig. 3A), and postoperative SNL was defined as the distance between the back of the glenosphere (position 1) and the most lateral edge of the infraglenoid tubercle (Fig. 3B). To assess inter-observer reliability, two orthopedic surgeons, each with at least 9 years of experience, independently performed the preoperative and postoperative SNL measurements.

Statistical analysis

Correlations between the preoperative and postoperative SNLs and position 1 impingement-free adduction were analyzed using Pearson’s correlation coefficient. Repeated-measures analysis of variance was performed for six positions of impingement-free adduction. Subsequent pairwise comparison among the six glenoid positions was performed with Tukey’s adjustment. The intraclass correlation coefficient was used to assess inter-observer reliability. A post-hoc power calculation was determined using the statistical power analyses G Power 3.1 software (http://www.psycho.uni-duesseldorf.de/abteilungen/aap/gpower3/) to eliminate type II errors. Statistical analyses were performed using IBM SPSS, version 23 (IBM, Armonk, NY, USA). The level of significance was set at $p < 0.05$.

Results

The mean glenoid width was 25.8 mm ± 2.8 mm (range, 22.6 mm to 31.1 mm), glenoid height was 34.1 mm ± 3.4 mm (range, 28.3 mm to 42.7 mm), glenoid version was 1.3 degrees ± 4.5 degrees (range, -4.7 degrees to 13.3 degrees) (+ : anteversion, - : retroversion), glenoid inclination was 10.4 degrees ± 4.2 degrees (range, 0 degrees to 18.1 degrees) (+ : superior tilt, - : inferior tilt), preoperative SNL was 8.2 mm ± 1.9 mm (range, 5.0 mm to 11.7 mm), and postoperative SNL was 6.0 mm ± 2.0 mm (range, 2.1 mm to 9.8 mm). The inter-observer reliability for preoperative SNL and postoperative SNL was 0.957 and 0.912, respectively. There was moderate correlation between the preoperative SNL and impingement-free adduction ($r = 0.628$, $p = 0.012$) (Fig. 4A), and there was a strong correlation between the postoperative SNL and impingement-free adduction ($r = 0.771$, $p = 0.001$) (Fig. 4B). Post-hoc power analysis showed a power >84% for detecting a significant difference.

The results of the comparison among the six positions for impingement-free adduction are summarized in Table I (repeated-measures analysis of variance, $p = 0.001$). Subsequent pairwise analysis revealed significant differences between all glenoid positions (between groups 3 and 4, $p = 0.004$; between the other groups, $p \leq 0.001$). Glenoid position 6, which is the most lateralized and inferiorized glenoid component, significantly increased impingement-free adduction.

Discussion

This study aimed to evaluate the influence of SNL on impingement-free adduction and to examine the effect of glenoid component lateralization and inferiorization on impingement-free adduction. The results showed that the SNL was correlated with impingement-free adduction. They also showed that the most lateralized and inferiorized offset had the maximum extent of impingement-free adduction.

Reverse total shoulder arthroplasty has achieved good results in treating painful glenohumeral arthritis with a rotator cuff deficiency.[5,6,13,29,30] However, scapular notching is one of the main complications that occurs following reverse total shoulder arthroplasty. Impingement on the scapular neck leads to scapular notching, and therefore we should anticipate possible impingement situations and place implants that are less likely to cause mechanical impingement during adduction of the shoulder joint.

Numerous factors influence mechanical impingement. Factors associated with the occurrence of impingement can be divided into three groups: patient-specific factors, factors related to surgical technique, and factors related to implant design.[26] Although the majority of the current research has been focused on the latter two factors, few studies have investigated potential patient-specific factors.

SNL is a patient-specific factor. Fortun et al.[4] reported a mean SNL of 10.6 mm using 442 dry cadaveric specimens. They mentioned that a reference from the most inferolateral edge of the glenoid fossa to the most lateral extent of the posterior column which was measured previously as SNL demonstrated significant variability. So they proposed functional SNL from the most lateral edge of the infraglenoid tubercle to the most inferolateral edge of the glenoid fossa. Thus, we defined the most lateral edge of the infraglenoid tubercle as the medial point of the SNL in this study. The inter-observer reliability for preoperative and postoperative SNL was good.

Paisley et al.[23] reported that the group with notching present had a significantly shorter SNL compared with the group with notching absent. It is suspected that short SNL may be a cause of scapular notching,[4,23] although no studies have investigated the changes of adduction due to variation in the SNL. We evaluated the influence of SNL on impingement-free adduction by using computer simulation and found that both preoperative and postoperative SNLs were positively correlated with impingement-free adduction. These results suggest that short SNLs have a tendency to cause impingement between the scapular neck and polyethylene cup. Thus, it may be important for the surgeon to measure the SNL preoperatively. After scouring the literature, we believe that the present study is the first to evaluate the influence of SNL on impingement-free adduction.

We found that the postoperative SNL had a stronger correlation with impingement-free adduction than the preoperative SNL. As Patel et al.[24] reported, increased medialization shortens the scapular neck, suggesting that medialization is associated with decreased impingement-free adduction. We therefore supposed that the postoperative SNL, which reflected the medialization after the glenoid was reamed, would show a stronger correlation than the preoperative SNL. On the basis of these findings, we assumed that it would be more effective to measure the SNL preoperatively to prevent postoperative scapular notching. This information may help the surgeon select the appropriate implant and determine whether to include bony lateralization or inferior eccentricity for patients with a short SNL postoperatively.

Previous studies reported an increase in ROM for lateralized and inferiorized offset separately,[1,3,7,8,16,19,31] but no reports have evaluated a combined lateralized and inferiorized offset. In present study, impingement-free adduction was minimum with glenoid position 1 (no bony lateralization with 0.5 mm inferior eccentricity) and maximum with glenoid position 6 (10 mm of bony lateralization with 4.5 mm inferior eccentricity). This result suggests that a combination of lateralization and inferiorization may be one option to reduce the risk of scapular notching. Theoretically, this improvement in adduction may reduce the incidence of scapular notching, although it should be noted that this lateralized and inferiorized offset has potentially greater loads transferred to the bone–prosthesis interface and may increase the risk of loosening glenoid components.[2,10,25] It may also increase the risk of acromial fracture because of the increased acromial stress.[9,32]

The current study has several limitations. First, this study investigated an onlay design prosthesis, the use of a single size glenosphere, the lack of an inlay design, and variation in baseplate version, inclination, and humeral retroversion. Second, we used a CT-based virtual computer model without any soft tissue or muscle. Thus, the impingement of soft tissue or muscle were not considered. Third, this study was focused specifically on the glenohumeral joint range of impingement-free adduction and not overall shoulder motion. Fourth, our computer simulation models consisted of normal shoulders. Thus, our results may not be applicable to all clinical situations in which reverse total shoulder arthroplasty is recommended, especially in cases of trauma or severe degenerative disease, in which we are not able to identify the infraglenoid tubercle.

Conclusions

We found that there was moderate correlation between the preoperative SNL and impingement-free adduction and a strong correlation between the postoperative SNL and impingement-free adduction. Although it should be noted that a lateralized and inferiorized center of rotation may increase the risk of loosening of the glenoid components, this offset significantly increased impingement-free adduction.

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Legends

Fig. 1. Glenoid reference coordinate system.

The x-axis was the line connecting the mid-point of the maximum anteroposterior glenoid width and the junction of the scapular spine and the vertebral border of the scapula. The z-axis was parallel to the perpendicular line from the inferior angle of the scapula to the x-axis. The y-axis was perpendicular to the x-axis and z-axis and passed through the origin.

Fig. 2. Glenoid position 1, no lateralization with A-offset (0.5-mm inferior eccentricity).

A baseplate was implanted so that its inferior edge was flush with the inferior edge of the glenoid, and the central boss was placed in the middle of the glenoid width, and the baseplate angle was 0° of version and 0° of inclination.

Fig. 3. (A) Preoperative SNL was defined as the distance between the articular surface of the glenoid and the most lateral edge of the infraglenoid tubercle. **(B)** Postoperative SNL was defined as the distance between the back of the glenosphere (position 1) and the most lateral edge of the infraglenoid tubercle.

Fig. 4. (A) Correlation between the preoperative scapular neck length (SNL) and impingement-free adduction (glenoid position 1), $r = 0.628$, $p = 0.012$. **(B)** Correlation between the postoperative SNL and impingement-free adduction (glenoid position 1), $r = 0.771$, $p = 0.001$.

Table I. Raw impingement-free adduction data (in degrees) based on glenoid positions 1 to 6 (lateralization and inferior eccentricity variables)

Fig. 1.

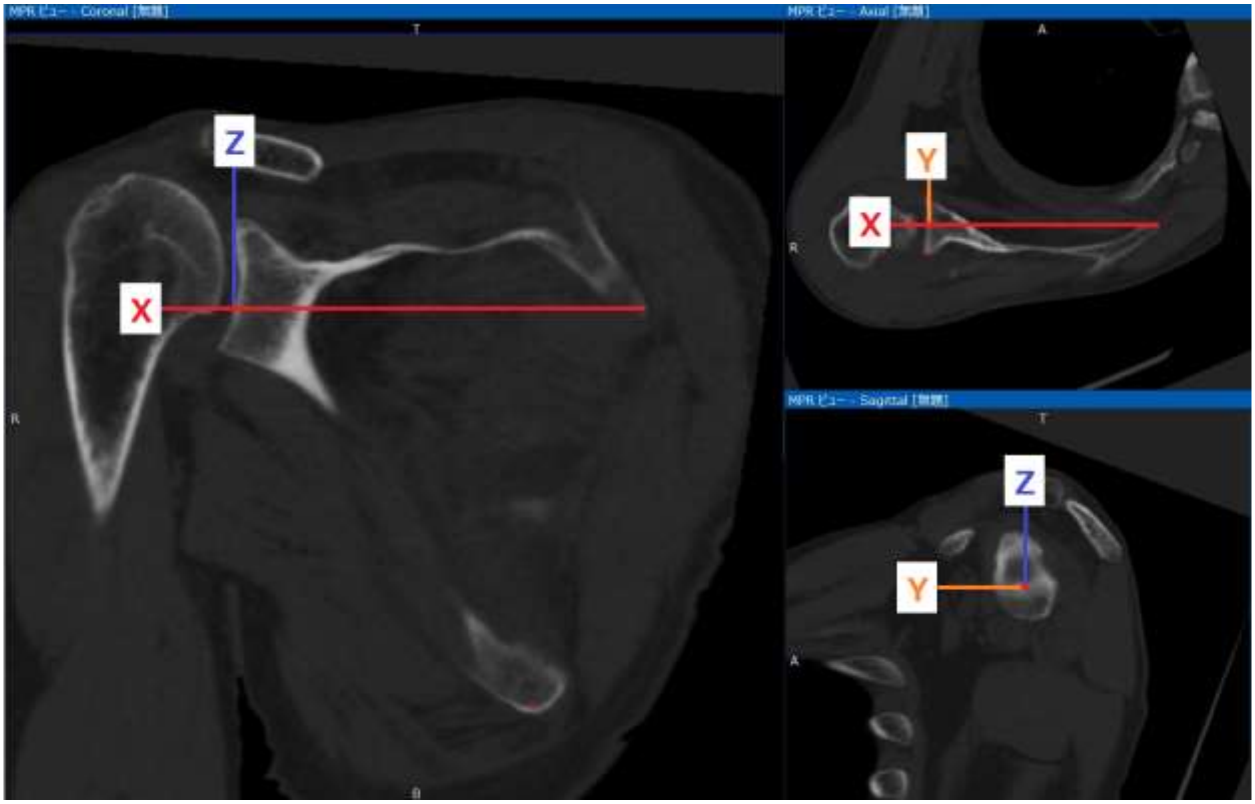
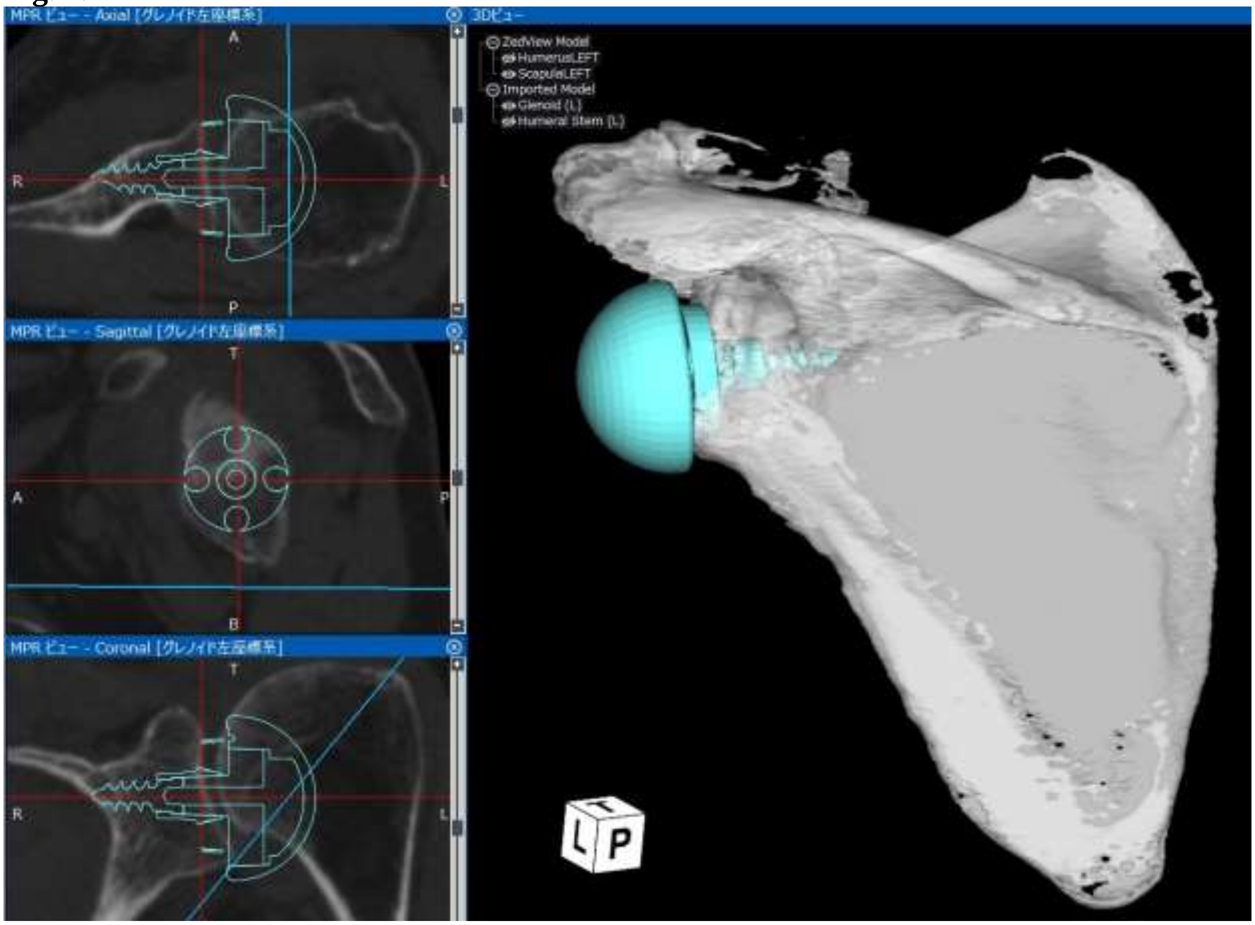
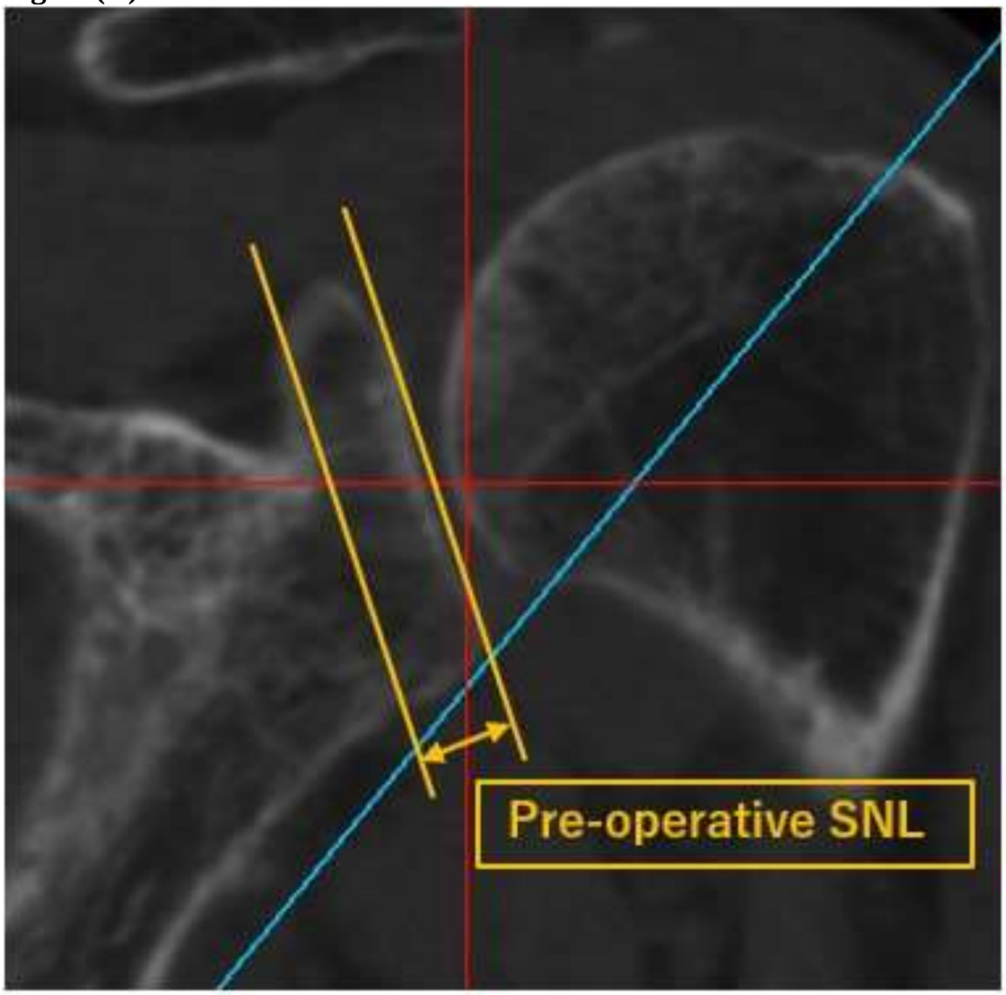


Fig. 2.

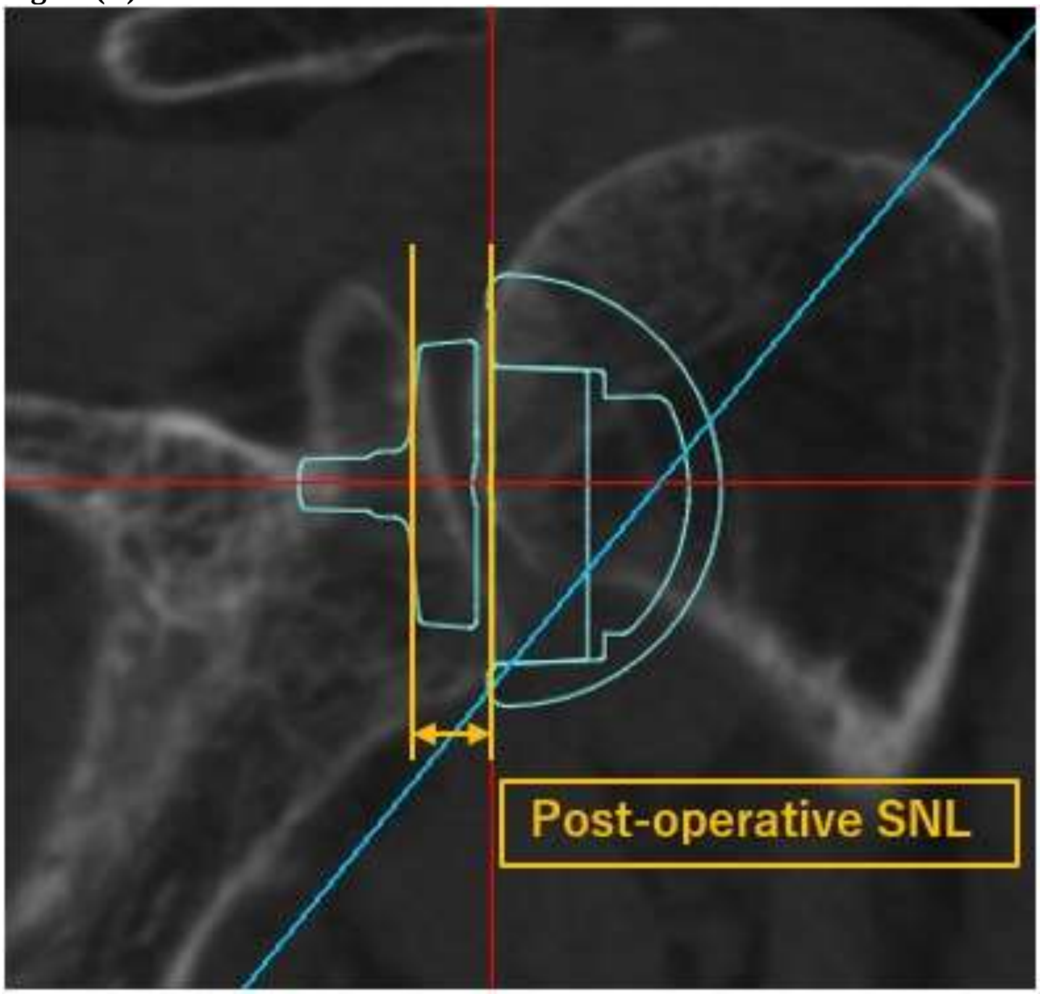

MPR ビュー - Axial [グレノイド左座標系]
3Dビュー
ZedView Model
HumerusLEFT
ScapulaLEFT
Imported Model
Glenoid (L)
Humeral Stem (L)
MPR ビュー - Sagittal [グレノイド左座標系]
MPR ビュー - Coronal [グレノイド左座標系]
L
T
P

371 **Fig. 3. (A)**



372

373 **Fig. 3. (B)**



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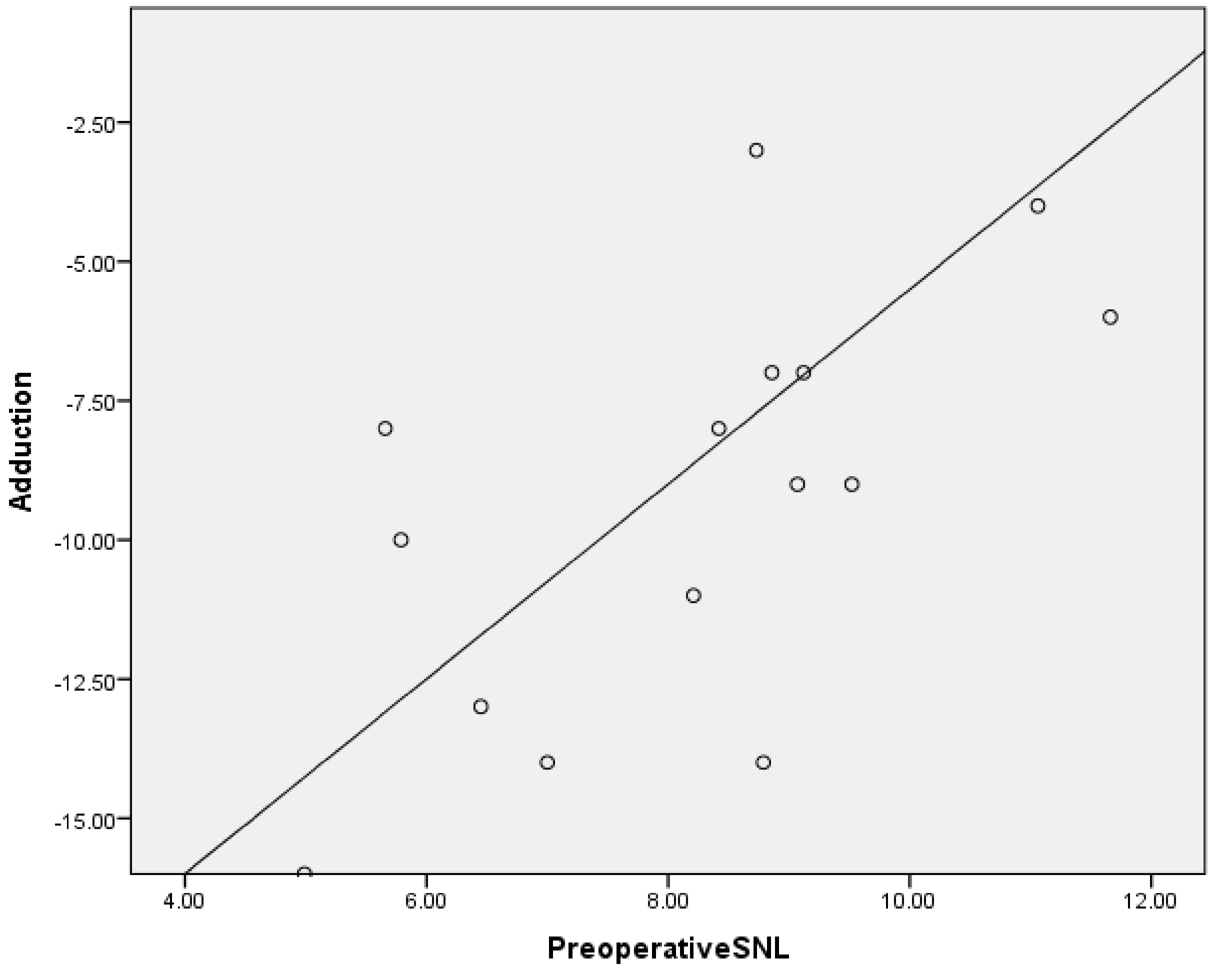
375 **Fig. 4. (A)**



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377

378 **Fig. 4. (B)**

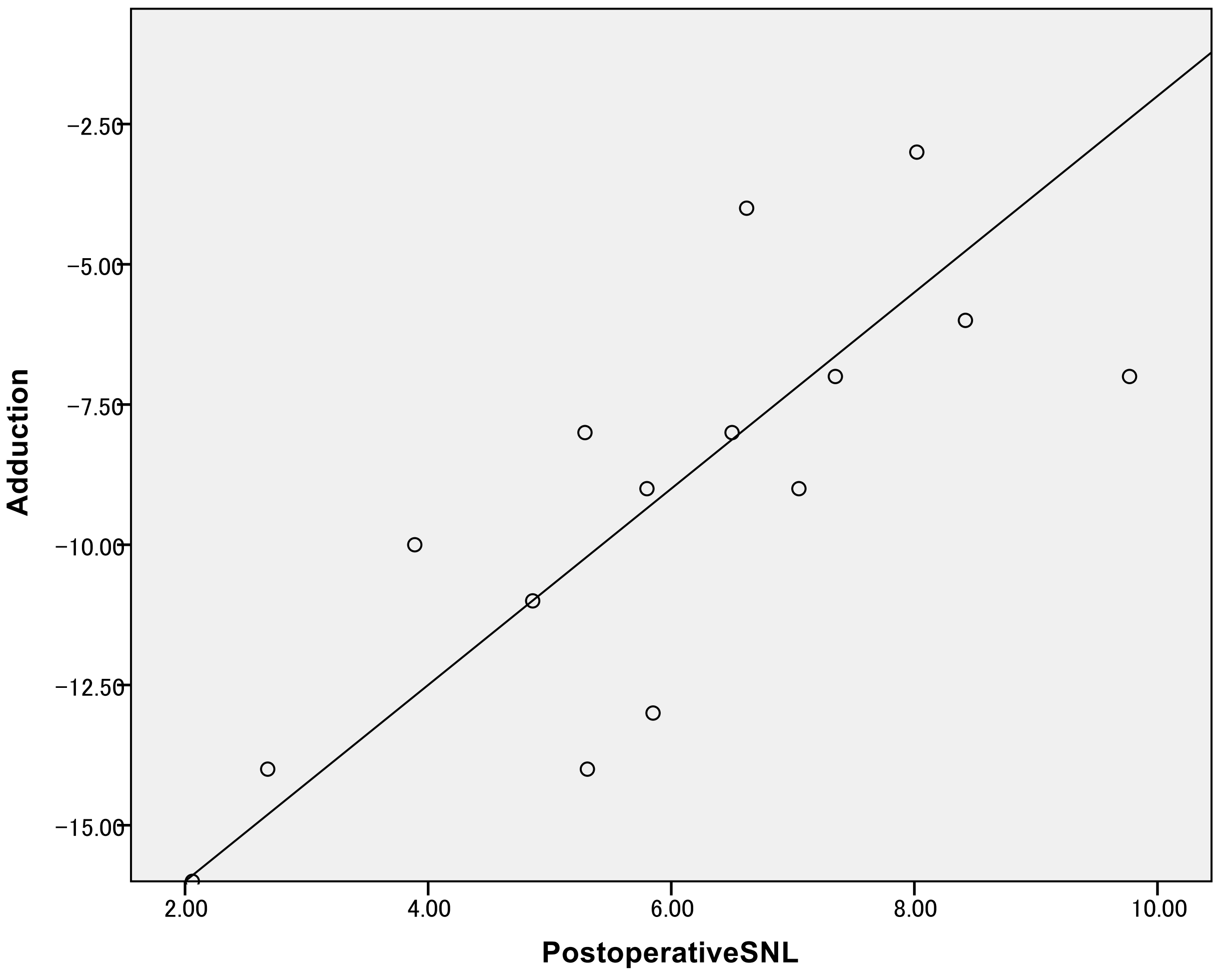

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Table I

Glenoid position	Bony lateralization (mm)	Inferior eccentricity (mm)	Impingement-free adduction (°)
1	0	0.5	-9.3 (3.6)
2	5	0.5	-1.5 (2.6)
3	10	0.5	5.1 (2.2)
4	0	4.5	2.5 (2.7)
5	5	4.5	11.5 (2.6)
6	10	4.5	17.7 (2.2)

Data are expressed as mean (standard deviation).