Association between Radiographic Parameters and Clinical Outcomes in Patients with Reverse Total Shoulder Arthroplasty

김 두 한

2022년 2월

박 사 학 위 논 문

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이 논문을 박사학위 논문으로 제출함

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외부 심사위원이신 최창혁 교수님, 이번 학위 논문 심사뿐만 아니라 항상 좋은 말씀과 격려로 정형외과 의사로서의 길을 잘 이끌어 주셔서 감사합니다. 이번 기회로 교수님과 더 깊은 인연을 맺을 수 있었다는 것은 저 개인적으로 큰 영광이었습니다.

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논문 작업에 집중할 수 있게 다방면에서 헌신적으로 도와준 정형외과 의국 식구들, 특히 김민지, 전은지, 이경진 양에게 고맙다는 말을 전하고 싶습니다. 기간 내에 학위 논문을 완성할 수 있었던 것은 오롯이 세 분의 도움 때문입니다. 어려운 부탁에도 항상 밝은 대답으로 힘이 되어 줘서 진심으로 고맙습니다.

정형외과 전문의가 된 후 지금까지 정형외과 의사로서의 어떤 삶을 살아야 할지 많은 고민을 하였습니다. 여러 가지 큰 결정을 앞에 두고, 잘할 자신이 없어 주저한 순간도 많았습니다. 그럴 때마다 늘 좋은 말로 격려해 주고, 인생의 방향을 결정할 수 있게 용기를 준 이수진 양에게도 가슴 깊이

감사의 뜻을 전하고 싶습니다. 내가 선택한 결정들과 내가 살고 있는 이 삶을 더 가치 있게 만들어주는 사람입니다. 저 역시 그런 사람이 되기 위해 많은 노력을 하겠습니다.

마지막으로 일이 바쁘다는 핑계로 여러 가지 소홀했던 점들이 많지만, 항상 전적으로 응원해 주시고 지지해 주시는 나의 부모님이신 김추진님, 강장순 여사님, 사랑하고 감사합니다. 어려운 여건 속에서도 부모님의 많은 헌신과 희생이 있었기에 지금의 제가 있다는 것을 너무나도 잘 알고 있습니다. 평생 잊지 않고 가슴속에 새기며 살아가겠으며, 부모님의 자녀로 부끄럽지 않는 사람이 되겠습니다.

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1. Introduction

Reverse total shoulder arthroplasty (RTSA), originally designed by Grammont and associates (1), reduced pain and restored shoulder motion in patients with irreparable cuff tears, rotator cuff arthropathy, and other complicated shoulder diseases (2-6). The indications for RTSA have recently been expanded to include active, higher-demand patients with shoulder pathologies. Although satisfactory clinical outcomes of RTSA have been demonstrated, the development of various complications (e.g., scapular notching, glenoid loosening, acromial stress fracture, and post-operative scapular fracture) can occur, and there are still poor outcomes despite the application of consistent technique by the surgeon (7-9). The original reverse prosthesis design, introduced by Dr. Paul Grammont in 1985, was based on several basic principles: [1] the center of rotation of the glenohumeral joint placed inferior and medial, [2] the implant must be essentially stable, [3] the deltoid muscle should be effective (10,11). Practically, however, there are many difficulties with regard to the methods for ideally assessing implant position in relation to anatomic characteristics.

Patient-related factors and multiple implant-related on both the glenoid and humeral sides play an important role in improving results. Many researches have recently been conducted to get better the design of the RTSA construct and surgical procedure to optimize results (12). Despite various studies, the optimum position of the implant for allowing maximum range of motion (ROM) and outcomes remains debated. In addition, there is some inconsistency in certain of these factors. For example, Sabesan et al. (12) suggested that lengthening of deltoid does not correlate with recovery in active ROM. In contrast, Jobin et al. (13)

concluded that deltoid lengthening improves active forward elevation after RTSA.

Furthermore, no comprehensive study on the association between various radiographic parameters and functional results has been conducted. The aim of this study was to analyze various radiographic parameters that may be predictive of clinical outcomes after RTSA. This study was conducted to verify the hypothesis that there would be several significant correlations between radiographic parameters and clinical outcomes following RTSA.

2. Materials and Methods

2.1. Patient Selection:

This paper was approved by the institutional review board of Dongsan hospital (IRB No: 2021-04-001). A total of 55 patients who underwent RTSA by a single surgeon between June 2010 and December 2017 with a minimum follow-up period of two years were included. Inclusion criteria were as follows: 1) patients with cuff tear arthropathy, 2) pseudoparesis with an irreparable massive rotator cuff tear. Painful pseudoparesis was defined as active shoulder forward flexion (FF) < 90 ° in the presence of full passive forward flexion. Exclusion criteria included patients who: 1) had a fracture or severe deformed osteoarthritis that is difficult to measure, 2) had revision RTSA or infection, 3) inadequate medical records (Figure 1).

2.2. Surgical Procedure and Rehabilitation:

The operation was undergone with the patients in the beach-chair position using the delto-pectoral approach. The TM reverse shoulder system (Zimmer, Warsaw, USA) was used in 21 cases, the Aequalis (Tornier, Montbonnot Saint Martin, France) in 21 cases, and the Equinoxe (Exactech, Gainesville, USA) in 13 cases. The operated shoulder was not mobilized in a sling for six weeks after surgery. Passive ROM exercises were started two weeks after surgery, and active ROM exercises were started six weeks after surgery.

2.3. Radiographical Measurements:

Radiographs included a true anteroposterior (AP) view of the glenohumeral joint in neutral rotation and an axial view of a computed tomography (CT) scan. Assessments were performed using the Infinitt PACS (Infinitt Healthcare Co., Seoul, South Korea) digital imaging system.

Radiographic parameters including critical shoulder angle (CSA), acromial index (AI), acromiohumeral interval (AHI), deltoid lever arm (DLA), acromial angulation (AA), Glenoid version (GV), and acromial height (AH) were evaluated for each patient before surgery. Postoperative measurements were repeated for CSA, AI, AHI, and DLA.

The CSA was measured in AP radiographs as described by Moor et al. (14). The CSA was defined as the angle between a line from the upper to the lower glenoid rim and a second line from the lower glenoid rim to the most lateral edge of acromion . The AI was defined as a ratio of the distance from the glenoid to the lateral edge of the acromion over the distance from the glenoid to the lateral edge of the greater tuberosity (Figure 2) (15). The AHI was measured by calculating the distance from the undersurface of the acromion to the greater tuberosity perpendicular to the long axis of the acromial body (15). The DLA was measured from the center of rotation (COR) perpendicularly to a line from the acromion to the deltoid tuberosity (12). The COR was measured as the center of a best-fit circle of the glenosphere (Figure 3) (12). The GV was measured as the angle between the glenoid line and the line perpendicular to the scapular axis (16). The glenoid line is measured connecting the anterior and posterior margins of the glenoid fossa, and the scapular axis is defined from the most medial aspect of the scapula body to the center of the glenoid fossa. The AA was measured in AP radiographs (16). The AA was defined as the angle between a line from the upper to the lower glenoid rim and a second line set on the undersurface of the acromial roof. The AH was defined in AP radiographs from the most inferior point of the glenoid to the undersurface of the acromial roof (Figure 4) (17).

All measurements were performed independently by two orthopedic surgeons blinded to clinical outcomes. And a randomized analysis was repeated by the investigators four weeks later for evaluation of interobserver reliability.

2.4. Clinical Outcomes and Ranges of Motion:

Clinical outcomes were assessed using a visual analog scale (VAS) for pain, the University of California at Los Angeles (UCLA) shoulder score, and American Shoulder and Elbow Surgeon (ASES) score. Active ROM was assessed FF, external rotation (ER) with the arm at the side, and internal rotation (IR) with the arm at the back. FF was measured in degrees between the thorax and the arm with the elbow held straight, and ER with 0 ° of shoulder abduction was assessed with the elbow in 90 ° of flexion between the forearm and the thorax. IR was measured using an indirect method called “hand behind the back” where the hand was placed behind the back, and the vertebral level reached by the tip of the extended thumb was measured. For statistical analysis of IR, values were converted into changed numbered groups: 1 to 12 for T1 to T12, 13 to 17 for L1 to L5, 18 for the sacrum, and 19 for the buttock (18). A clinical examination was performed by an independent study coordinator, and these scores and ROMs were obtained at routine preoperative and postoperative clinic visits.

2.5. Statistical Physics Analysis:

IBM SPSS ver. 25.0 (IBM Co., Armonk, NY, USA) was used for all data analyses. Inter- and intra-rater reliability were assessed by calculating the Fleiss k correlation coefficient (19). The interpretation of the strength of agreement determined by the k values was dependent on the criteria of Landis and Koch (20) : values of 0 to 0.20, slight agreement; 0.21 to 0.40, fair agreement; 0.41 to 0.60, moderate agreement; 0.61 to 0.80, substantial agreement; and 0.81 to 1.00 indicate almost perfect agreement. The paired t-test was used for comparison of the pre-operative and final clinical scores and ROMs. Pearson correlation co-efficients were used to examine the relationships between radiographic parameters and clinical outcomes. The variation in ROM and clinical outcomes was examined using receiver operating characteristic curves to establish cut scores for each radiographical parameter that influenced the recorded outcomes. Statistical significance was defined at $p < 0.05$ for all statistical comparisons and additionally for the receiver operating characteristic curve analysis of a minimum area under the curve (AUC) > 0.60 (15).

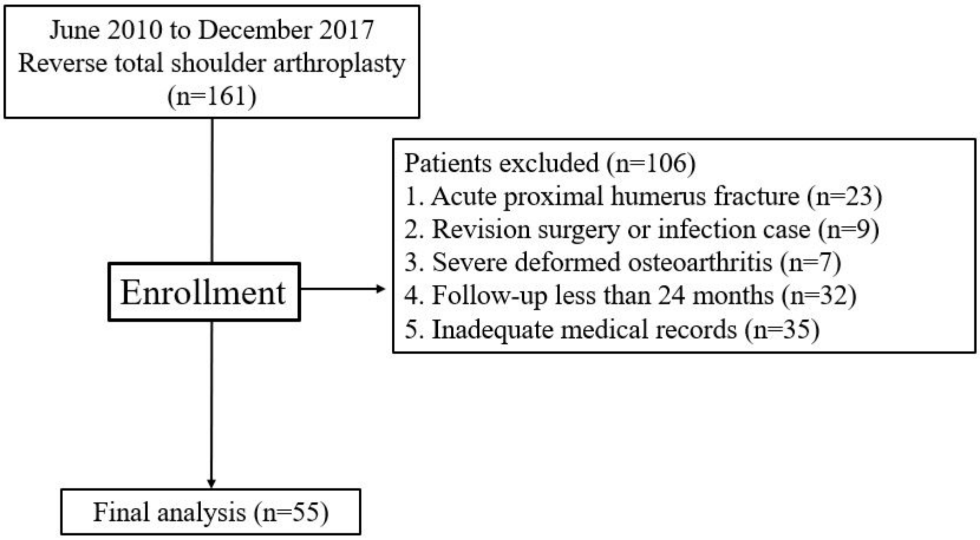

Figure 1. Patient's flow chart. A total of 55 patients who underwent reverse total shoulder arthroplasty by a single surgeon between June 2010 and December 2017 with a minimum follow-up period of two years were included.

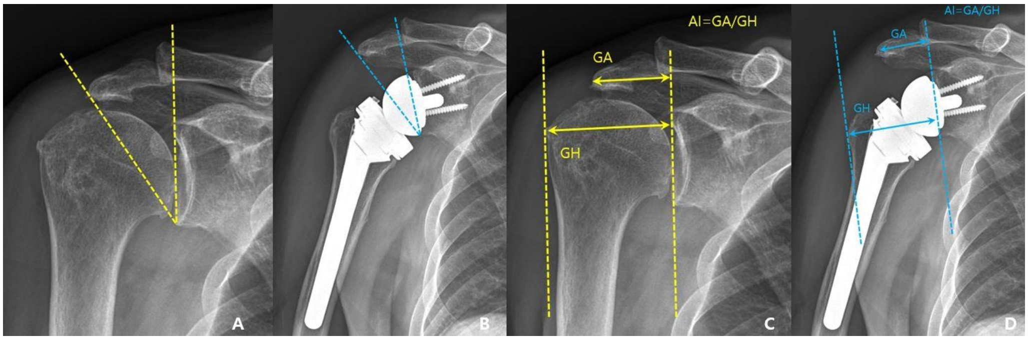

Figure 2. Radiographical measurement Ⅰ. (A) Preoperative critical shoulder angle. (B) Postoperative critical shoulder angle. (C) Preoperative acromial index. (D) Postoperative acromial index. AI: acromial index; GA: the distance from the glenoid to the lateral edge of the acromion; GH: the distance from the glenoid to the lateral edge of the greater tuberosity.

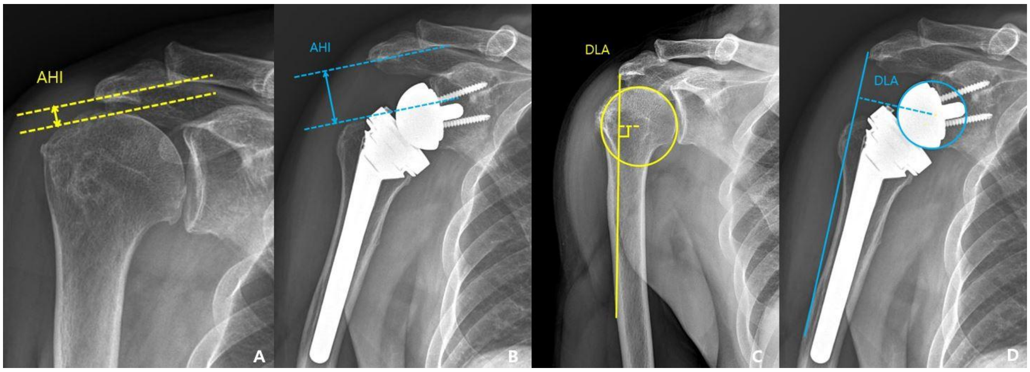

Figure 3. Radiographical measurement Ⅱ. (A) Preoperative acromio-humeral interval. (B) Postoperative acromiohumeral interval. (C) Preoperative deltoid lever arm. (D) Postoperative deltoid lever arm. AHI: acromiohumeral interval; DLA: deltoid lever arm.

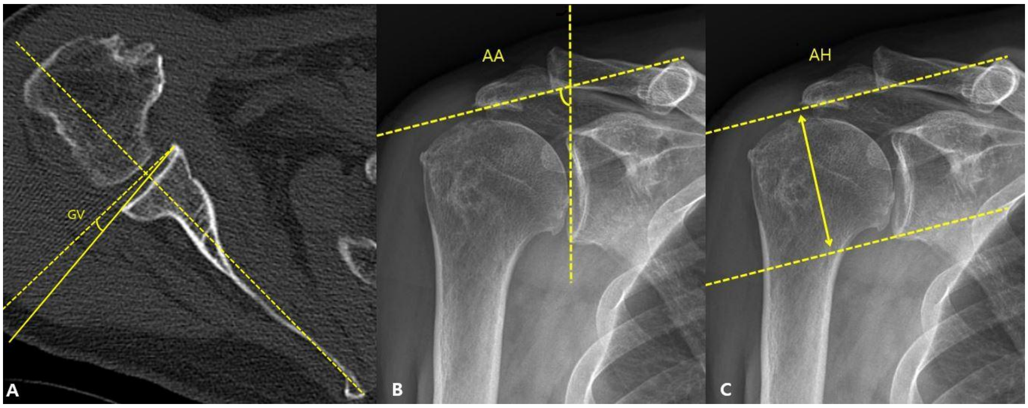

Figure 4. Radiographical measurement Ⅲ. (A) Glenoid version. (B) Acromial angulation. (C) Acromial height. AA: acromial angulation; AH: acromial height; GV: Glenoid version.

3. Results

Overall, 55 RTSAs were evaluated, including 13 males and 42 females with a average age of 72.0 ± 9.5 years (range, 60-83 years). The average follow-up period was 40.0 ± 15.1 months (range, 24-93 months). Implants were used 39 right shoulders and 16 left shoulders. Of the patients, 33 were rotator cuff tear arthropathy, and 22 were massive rotator cuff tears (Table 1). Inter-rater and intra-rater reliability were calculated for all measured radiographical parameters. Most of the parameters showed excellent reliability. Good interclass correlation coefficient (ICC) was found for AA, and fair to good ICC was found for GV (Table 2).

Overall, a significant change in CSA, AHI, and DLA was observed between preoperative and postoperative measurements. In addition, there was a significant improvement in all clinical outcomes and ROMs from preoperative to postoperative (Table 3&4).

The details of the associated p values and correlations are described in Table 5. Postoperative AHI had a significant correlation with FF ($r = -0.270$; $p < 0.05$), ER ($r = -0.421$; $p < 0.01$), and IR ($r = 0.275$; $p < 0.05$) at final follow-up. In addition, GV showed a significant negative correlation with UCLA score ($r = -0.292$; $p < 0.05$).

A contingency table was used to evaluate the predictive value of the postoperative AHI on the ability to obtain 130 ° of FF, 45 ° of ER, and 14 of IR. If the AHI was greater than 29 mm, there was a 50% chance of obtaining at least 130 ° of FF and a 56% chance of obtaining at least 45 ° of ER. If the distance was less, there was an 86% chance of more than 130 ° of FF (AUC 0.688, 95% confidence interval (CI) 0.522-0.853, $p < 0.05$) and an 86% chance of obtaining at least 45 ° of ER (AUC

0.689, 95% CI 0.515-0.862, $p < 0.05$). However, no significant correlation was found between increased IR and AHI (AUC 0.612, 95% CI 0.451-0.773, $p > 0.05$) (Figure 5).

Scapular notching was observed in 25 shoulders. According to the Sirveaux classification (21). it was confirmed grade 1 in 20 cases, grade 2 in three cases, and grade 3 in two cases. There were three cases of brachial plexus nerve palsy. All patients recovered spontaneously at one, two, and four months after surgery, respectively. However, no severe or systemic complication occurred in any of the patients.

Table 1. Demographics Data

Clinical characteristic	
Age (year)	72.0 ± 5.3
Sex (male/female)	13 / 42
BMI (kg/m^2)	24.7 ± 3.8
Follow-up (months)	40.0 ± 15.1
Affected arm (right/left)	39 / 16
Diagnosis	
Cuff tear arthropathy	33
Massive rotator cuff tear	22

BMI: body mass index.

Table 2. Inter- and Intra-rater Reliability for All Radiographic Measurements and Mean Values for Radiographic Analysis

	Inter ICC	95% CI	Intra ICC	95% CI	Reliability
Preoperative CSA	0.804	[0.704-0.870]	0.801	[0.699-0.868]	Excellent
Postoperative CSA	0.875	[0.812-0.917]	0.936	[0.901-0.959]	Excellent
Preoperative AI	0.828	[0.740-0.886]	0.893	[0.839-0.929]	Excellent
Postoperative AI	0.894	[0.840-0.930]	0.976	[0.963-0.984]	Excellent
Preoperative AHI	0.734	[0.680-0.772]	0.853	[0.776-0.903]	Good-Excellent
Postoperative AHI	0.779	[0.718-0.820]	0.861	[0.788-0.908]	Excellent
Preoperative DLA	0.813	[0.718-0.876]	0.917	[0.875-0.945]	Excellent
Postoperative DLA	0.831	[0.689-0.901]	0.945	[0.901-0.968]	Excellent
Acromial angulation	0.704	[0.618-0.766]	0.719	[0.639-0.776]	Good
Glenoid version	0.451	[0.384-0.499]	0.600	[0.440-0.705]	Fair-Good
Acromial height	0.913	[0.868-0.942]	0.935	[0.902-0.957]	Excellent

AHI: acromiohumeral interval; AI: acromial index; CI: confidence interval; CSA: critical shoulder angle; DLA: deltoid lever arm; ICC: interclass correlation coefficient.

Table 3. Radiographic Variables: Preoperative, Postoperative, and Change

	Preoperative	Postoperative	Change	p-value
Critical shoulder angle (°)	35.9 ± 3.7	31.7 ± 5.3	-4.2 ± 6.0	< 0.001 *
Acromial index	0.72 ± 0.09	0.70 ± 0.12	-0.02 ± 0.12	> 0.05
Acromiohumeral interval (mm)	7.3 ± 2.9	27.8 ± 6.0	20.5 ± 5.7	< 0.001 *
Deltoid lever arm (mm)	14.2 ± 5.1	41.0 ± 5.1	26.9 ± 5.3	< 0.001 *
Acromial angulation (°)	77.1 ± 7.1	-	-	-
Acromial height (mm)	54.0 ± 4.5	-	-	-
Glenoid version (°)	0.4 ± 3.8	-	-	-

*: Statistically significant.

Table 4. Clinical Outcomes and Range of Motions: Preoperative, Postoperative, and Change

	Preoperative	Postoperative	Change	p-value
VAS	7.0 ± 2.2	1.2 ± 1.8	-5.8 ±2.7	< 0.001 *
UCLA	12.4 ± 4.8	28.4 ± 4.4	16.1 ± 6.2	< 0.001 *
ASES	29.1 ± 15.8	82.4 ± 16.5	53.3 ± 21.1	< 0.001 *
Forward flexion (°)	70.0 ± 41.7	141.1 ± 20.5	71.5 ± 44.1	< 0.001 *
External rotation at side (°)	22.8 ± 19.6	50.8 ± 13.4	28.0 ± 23.7	< 0.001 *
Internal rotation at back	15.4 ± 2.3	14.2 ± 1.7	-1.16 ± 2.6	< 0.001 *

ASES: American Shoulder and Elbow Surgeon; UCLA: University of California at Los Angeles; VAS: visual analog scale. *: Statistically significant.

Table 5. Correlations and p-values of All Radiographic Measurements and Final Functional Outcomes

	VAS score		UCLA score		ASES score		Forward flexion		External rotation		Internal rotation	
	r value	p-value	r value	p-value	r value	p-value	r value	p-value	r value	p-value	r value	p-value
Preoperative CSA	0.010	> 0.05	-0.022	> 0.05	-0.033	> 0.05	-0.036	> 0.05	-0.140	> 0.05	0.185	> 0.05
Postoperative CSA	-0.102	> 0.05	0.108	> 0.05	0.057	> 0.05	0.255	> 0.05	0.008	> 0.05	0.086	> 0.05
Acromial index	-0.028	> 0.05	0.084	> 0.05	0.062	> 0.05	0.038	> 0.05	-0.063	> 0.05	0.141	> 0.05
Glenoid height	-0.080	> 0.05	0.037	> 0.05	-0.017	> 0.05	0.216	> 0.05	-0.002	> 0.05	0.080	> 0.05
Preoperative AHI	0.009	> 0.05	-0.003	> 0.05	0.029	> 0.05	-0.107	> 0.05	-0.003	> 0.05	-0.002	> 0.05
Postoperative AHI	0.076	> 0.05	-0.176	> 0.05	-0.102	> 0.05	-0.270	< 0.05 *	-0.421	< 0.01 *	0.275	< 0.05 *
Preoperative DLA	0.064	> 0.05	0.029	> 0.05	-0.002	> 0.05	-0.083	> 0.05	-0.055	> 0.05	0.187	> 0.05
Postoperative DLA	-0.010	> 0.05	-0.077	> 0.05	0.009	> 0.05	-0.160	> 0.05	-0.232	> 0.05	0.235	> 0.05
Acromial angulation	-0.061	> 0.05	0.063	> 0.05	0.071	> 0.05	0.127	> 0.05	0.092	> 0.05	-0.142	> 0.05
Glenoid version	0.252	> 0.05	-0.292	< 0.05*	-0.245	> 0.05	-0.092	> 0.05	0.015	> 0.05	-0.047	> 0.05
Acromial height	-0.070	> 0.05	0.073	> 0.05	0.124	> 0.05	0.047	> 0.05	0.009	> 0.05	0.111	> 0.05

AHI: acromiohumeral interval; ASES: American Shoulder and Elbow Surgeon; CSA: critical shoulder angle; DLA: deltoid lever arm; UCLA: University of California at Los Angeles; VAS: visual analog scale. *: Statistical significance.

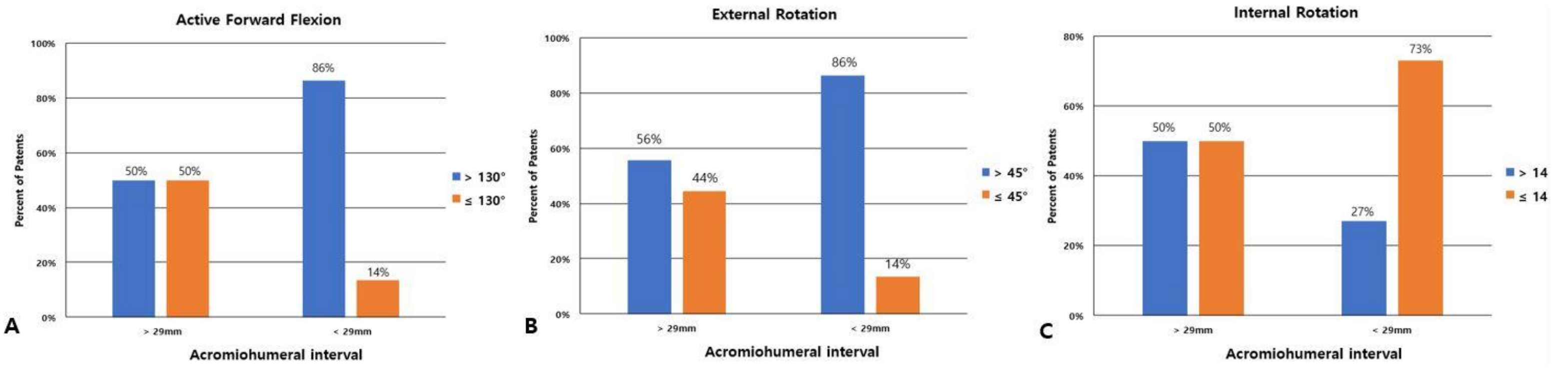

Figure 5. The predictive value of postoperative acromiohumeral interval. When the postoperative acromiohumeral interval was < 29 mm, then (A) nearly 86% of patients achieved > 130 ° of active forward flexion. (B) Nearly 86% of patients achieved > 45 ° of external rotation. (C) Nearly 73% of patients achieved ≤ 14 of internal rotation.

4. Discussion

The current study was performed in order to identify radiographic parameters that may be associated with the clinical outcomes in patients after RTSA. The main finding was that postoperative AHI showed an association with ROMs at the final follow-up. However, the other radiographic parameters showed no association with clinical outcomes and ROMs. In particular, this study showed that 86% of included patients with an AHI of 29 mm or less were able to achieve 130 ° of FF and 45 ° ER at the final follow-up.

There is still considerable debate regarding the radiographic parameter of RTSA for optimal restoration of function while maintaining longevity. Distalization of the COR is needful to provide space for unrestricted ROM of the humeral motion and the deltoid muscle tension. Deltoid muscle with ideal tension provides the stable fulcrum necessary for the stability of the prosthesis and active movement of the shoulder. However, over-lengthening is not helpful because it could worsen the possibility of complications such as nerve injury, fixed abduction of the arm, or postoperative acromial stress fracture (22-24). Additionally, failure to restore adequate deltoid muscle tension may occur in poor clinical outcomes (25). Studies on the appropriate degree of distalization are still in progress and have been conducted using arm length, deltoid length, and AHI.

Ledermann et al. (25) used arm length to confirm correlation with clinical outcomes and retrospectively reviewed 183 RTSA cases. They concluded no correlation between improvements in ROM and arm lengthening. However, better clinical outcomes were found with arm lengthening than shortening. In addition, they recommended that lengthening above 25 mm compared with the contralateral side should not be a surgical target. And Gerber et al. (26) also proposed a 20 to 30 mm lengthening, as assessed with palpation from the lateral edge of the acromion to the elbow.

Deltoid muscle lengthening is recognized empirically as a critical fuctional attribute. Jobin et al. (13) prospectively evaluated 49 shoulders undergoing RTSA. In their study, a strong correlation was observed between deltoid lengthening and active FF of the shoulder. However, they did not observe over tension-related complications or discover a plateau effect of deltoid muscle lengthening on FF. A study showing the opposite result has been reported. Sabesan et al. conducted a multi-center study of RTSA comparing the relationship between deltoid muscle lengthening with functional results. As a result, they found that deltoid lengthening showed no correlation with improvements in active FF or ER (12).

The AHI depends on the thickness and size of the prosthesis, an eccentric center of glenosphere, and the location of the glenosphere implant in the sagittal plane (25). In a multi-center study involving the AHI, Berthold et al. investigated the prognostic radiographic factors affecting functional results in patients with RTSA using a 135 ° implant design (27). They found that postoperative AHI showed significant correlations with FF and the clinical score. However, other radiographic variables were negligible or not significant.

Although several studies have reported an association of implant design with postoperative clinical outcomes, these results were controversial. Excessive lateralization of the humeral head can effect in higher forces and soft tissue tension by deltoid muscle, leading to an increased risk of an acromial stress fracture (28-31). The AI (glenoid-acromial distance /glenohumeral distance) would represent lateralization of the humerus in this study. Roberson et al. (15) found that postoperative AI of > 0.62 correlated with ASES score and Penn Shoulder Score, which were 10 points higher than for RTSA patients with an AI of < 0.6. Lateralization of the implant's COR has been proposed to reduce scapular notching, improve deltoid tension, and increase shoulder ROM (31). COR or DLA of the glenohumeral joint may represent a medializing of the COR. Greiner et al. (32) performed prospective research comparing the functional outcomes of non-lateralized versus lateralized RTSA using a 10 mm-autogenous bone graft. They found a significant improvement in ROM in the lateralized group. However, Jobin et al. (13) found no functional correlation with the COR. Although no significant differences between radiographic parameters related to the medialized COR and lateralization of the humerus and clinical outcomes were observed in this study, there was a substantial difference with the implant types. The TM reverse shoulder system and the Equinoxe demonstrated a substantial improvement in ER of the shoulder as compared to the Aequalis ($p < 0.05$, $p < 0.05$, respectively). ER could be related to lateralized implant type in this study. The TM reverse shoulder system is a more lateralized glenoid implant than Aequalis. Equinoxe is a more lateralized humeral implant than Aequalis. But, no significant difference in clinical outcomes was found with the use of these three implant types.

This study has a few limitations. First, it is retrospective and has limitations similar to those of other retrospective studies. However, a retrospective analysis of the prospectively collected clinical data was conducted. Second, the number of included patients was relatively small (55 patients). Third, this study conducted only an Asian population of patients who underwent surgery in South Korea. As such, the results may only be generalizable to a similar population. The conduct of further studies in various ethnic groups is needed. Nevertheless, the strength of this study is that the study was conducted in a homogenous group of patients with RTSA performed by a single surgeon and included comprehensive radiographic parameters.

5. Summary

This study aimed to analyze various radiographic parameters that may be predictive of clinical outcomes after RTSA. Fifty-five patients treated with RTSA were enrolled. A total of 55 patients who underwent RTSA by one surgeon between June 2010 and December 2017 with a minimum two-year follow-up period were included. Inter-rater and intra-rater reliability were calculated for all measured radiographical parameters. Most of the parameters showed excellent reliability. Postoperative AHI revealed a significant correlation with FF ($r = -0.270$; $p < 0.05$), ER ($r = -0.421$; $p < 0.01$), and IR ($r = 0.275$; $p < 0.05$) at final follow-up. In addition, excessive distalization reduced FF and ER motion of the shoulder in patients who underwent RTSA. Therefore, surgeons must consider and be critical of excessive lengthening of the deltoid muscle, which can also have poor outcomes or complications. The conduct of a well-designed prospective study is needed in order to understand the association between comprehensive radiographic parameters and clinical outcomes.

References

1. Grammont PM, Baulot E: The classic: Delta shoulder prosthesis for rotator cuff rupture. 1993. Clin Orthop Relat Res 2011; 469: 2424.

2. Deshmukh AV, Koris M, Zurakowski D, Thornhill TS: Total shoulder arthroplasty: long-term survivorship, functional outcome, and quality of life. J Shoulder Elbow Surg 2005; 14: 471-9.

3. Nolan BM, Ankerson E, Wiater JM: Reverse total shoulder arthroplasty improves function in cuff tear arthropathy. Clin Orthop Relat Res 2011; 469: 2476-82.

4. Kim JY, Rhee YG, Rhee SM: Clinical outcomes after reverse total shoulder arthroplasty according to primary diagnosis. Clin Orthop Surg 2020; 12: 521-8.

5. Kim J, Ryu Y, Kim SH: Surgical options for failed rotator cuff repair, except arthroplasty: Review of current methods. Clin Shoulder Elb 2020; 23: 48-58.

6. Collotte P, Bercik M, Vieira TD, Walch G: Long-term reverse total shoulder arthroplasty outcomes: The effect of the inferior shifting of glenoid component fixation. Clin Orthop Surg 2021; 13: 505-12.

7. Schwartz DG, Cottrell BJ, Teusink MJ, Clark RE, Downes KL, Tannenbaum RS, et al.: Factors that predict postoperative motion in patients treated with reverse shoulder arthroplasty. J Shoulder Elbow

Surg 2014; 23: 1289-95.

8. Cho CH, Jung JW, Na SS, Bae KC, Lee KJ, Kim DH: Is Acromial fracture after reverse total shoulder arthroplasty a negligible complication?: A systematic review. Clin Orthop Surg 2019; 11: 427-35.

9. Kim SC, Kim IS, Jang MC, Yoo JC: Complications of reverse shoulder arthroplasty: a concise review. Clin Shoulder Elb 2021; 24: 42-52.

10. Grammont P, Trouilloud P, Laffay J, Deries X: Etude et réalisation d'une nouvelle prothèse d'épaule. Rhumatologie 1987; 39: 407-18.

11. Berliner JL, Regalado-Magdos A, Ma CB, Feeley BT: Biomechanics of reverse total shoulder arthroplasty. J Shoulder Elbow Surg 2015; 24: 150-60.

12. Sabesan VJ, Lombardo D, Josserand D, Buzas D, Jelsema T, Petersen-Fitts GR, et al.: The effect of deltoid lengthening on functional outcome for reverse shoulder arthroplasty. Musculoskelet Surg 2016; 100: 127-32.

13. Jobin CM, Brown GD, Bahu MJ, Gardner TR, Bigliani LU, Levine WN, et al.: Reverse total shoulder arthroplasty for cuff tear arthropathy: the clinical effect of deltoid lengthening and center of rotation medialization. J Shoulder Elbow Surg 2012; 21: 1269-77.

14. Moor BK, Bouaicha S, Rothenfluh DA, Sukthankar A, Gerber C: Is there an association between the individual anatomy of the scapula and the development of rotator cuff tears or osteoarthritis of the

glenohumeral joint?: A radiological study of the critical shoulder angle. Bone Joint J 2013; 95-B: 935-41.

15. Roberson TA, Shanley E, Abildgaard JT, Granade CM, Adams KJ, Griscom JT, et al.: The influence of radiographic markers of bio-mechanical variables on outcomes in reverse shoulder arthroplasty. JSES Open Access 2019; 3: 59-64.

16. Incesoy MA, Yildiz KI, Turk OI, Akinci S, Turgut E, Aycan OE, et al.: The critical shoulder angle, the acromial index, the glenoid version angle and the acromial angulation are associated with rotator cuff tears. Knee Surg Sports Traumatol Arthrosc 2021; 29: 2257-63.

17. Beeler S, Hasler A, Gotschi T, Meyer DC, Gerber C: Critical shoulder angle: Acromial coverage is more relevant than glenoid inclination. J Orthop Res 2019; 37: 205-10.

18. Oh JH, Kim SH, Lee HK, Jo KH, Bin SW, Gong HS: Moderate preoperative shoulder stiffness does not alter the clinical outcome of rotator cuff repair with arthroscopic release and manipulation. Arthroscopy 2008; 24: 983-91.

19. Venkataraman G, Ananthanarayanan V, Paner GP: Accessible calculation of multirater kappa statistics for pathologists. Virchows Arch 2006; 449: 272.

20. Landis JR, Koch GG: The measurement of observer agreement for categorical data. Biometrics 1977; 33: 159-74.

21. Sirveaux F, Favard L, Oudet D, Huquet D, Walch G, Mole D: Grammont inverted total shoulder arthroplasty in the treatment of glenohumeral osteoarthritis with massive rupture of the cuff. Results of a multicentre study of 80 shoulders. J Bone Joint Surg Br 2004; 86: 388-95.

22. Boileau P, Watkinson DJ, Hatzidakis AM, Balg F: Grammont reverse prosthesis: design, rationale, and biomechanics. J Shoulder Elbow Surg 2005; 14: 147S-61S.

23. Ladermann A, Williams MD, Melis B, Hoffmeyer P, Walch G: Objective evaluation of lengthening in reverse shoulder arthroplasty. J Shoulder Elbow Surg 2009; 18: 588-95.

24. Ladermann A, Lubbeke A, Melis B, Stern R, Christofilopoulos P, Bacle G, et al.: Prevalence of neurologic lesions after total shoulder arthroplasty. J Bone Joint Surg Am 2011; 93: 1288-93.

25. Ladermann A, Walch G, Lubbeke A, Drake GN, Melis B, Bacle G, et al.: Influence of arm lengthening in reverse shoulder arthroplasty. J Shoulder Elbow Surg 2012; 21: 336-41.

26. Gerber C, Pennington SD, Nyffeler RW: Reverse total shoulder arthroplasty. J Am Acad Orthop Surg 2009; 17: 284-95.

27. Berthold DP, Morikawa D, Muench LN, Baldino JB, Cote MP, Creighton RA, et al.: Negligible correlation between radiographic measurements and clinical outcomes in patients following primary reverse total shoulder arthroplasty. J Clin Med 2021; 10: 809.

28. Henninger HB, Barg A, Anderson AE, Bachus KN, Burks RT, Tashjian RZ: Effect of lateral offset center of rotation in reverse total shoulder arthroplasty: a biomechanical study. J Shoulder Elbow Surg 2012; 21: 1128-35.

29. Henninger HB, King FK, Tashjian RZ, Burks RT: Biomechanical comparison of reverse total shoulder arthroplasty systems in soft tissue-constrained shoulders. J Shoulder Elbow Surg 2014; 23: e108-17.

30. Chan K, Langohr GDG, Mahaffy M, Johnson JA, Athwal GS: Does humeral component lateralization in reverse shoulder arthroplasty affect rotator cuff torque? evaluation in a cadaver model. Clin Orthop Relat Res 2017; 475: 2564-71.

31. Sheth U, Saltzman M: Reverse total shoulder arthroplasty: Implant design considerations. Curr Rev Musculoskelet Med 2019; 12: 554-61.

32. Greiner S, Schmidt C, Herrmann S, Pauly S, Perka C: Clinical performance of lateralized versus non-lateralized reverse shoulder arthroplasty: a prospective randomized study. J Shoulder Elbow Surg 2015; 24: 1397-404.

Association between Radiographic Parameters and Clinical Outcomes in Patients with Reverse Total Shoulder Arthroplasty

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(Abstract)

Reverse total shoulder arthroplasty (RTSA) improves function and reduces pain for patients with complex shoulder problems. However, there is a lack of literature regarding the association of radiographic parameters on clinical outcomes after RTSA. The aim of this study was to analyze various radiographic parameters that may be predictive of clinical outcomes after RTSA. A total of 55 patients treated with RTSA were enrolled. Shoulder radiographic parameters were used for measurement of critical shoulder angle (CSA), acromial index, acromiohumeral interval (AHI), deltoid lever arm (DLA), acromial angulation, glenoid version, and acromial height. Preoperative and postoperative clinical outcomes were evaluated at a minimum 2-year follow-up. A significant

correlation of postoperative AHI with forward flexion, external rotation, and internal rotation was observed at final follow-up. In addition, post-operative AHI less than 29 mm had an 86% positive predictive value of obtaining 130 ° of forward flexion and 45 ° of external rotation. It was found that postoperative AHI showed an association with active range of motion in patients who underwent RTSA. In particular, excessive distalization reduced forward flexion and external rotation motion of the shoulder in patients treated with RTSA.

역행성 견관절 전치환술 환자의 방사선학적 지표와 임상적인 결과 간의 상관관계

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(초록)

복합성 어깨 질환을 가진 환자에 있어서 역행성 견관절 전치환술은 환자의 통증을 줄여주고 어깨의 기능을 회복시켜준다. 그러나 역행성 견관절 전치환술 환자의 여러 가지 방사선학적 지표와 임상적인 결과에 관한 연구는 거의 없다. 본 연구의 목적은 역행성 견관절 전치환술 후 다양한 방사선학적 지표를 분석하여 임상적인 결과를 예측할 수 있을지 알아보고자 하였다. 역행성 견관절 전치환술을 시행받은 55명의 환자를 연구에 포함되었다. 어깨의 방사선학적 지표로 critical shoulder angle (CSA), acromial index, acromiohumeral interval (AHI), deltoid lever arm (DLA), acromial angulation, glenoid version, and acromial height를 사용하였다. 수술 전 후 임상적인 평가는 최소 2년 이상 추시관찰 하였다. 수술 후 AHI는 최종 추시 결과의 어깨의 전방거상, 외회전, 내회전에서 유의한 상관관계가 있었다. 추가적인 분석으로 수술 후 AHI가 29 mm 이하인 군에서 86%의 양성예측율

로 130° 이상 전방 거상과 45° 이상의 외회전이 측정되었다. 본 연구에서 수술 후 AHI는 역행성 견관절 전치환술 환자의 능동적 어깨 관절 운동과 연관성이 있었다. 특히 과도한 견관절의 원위전위는 환자의 어깨 전방거상 및 외회전을 감소시키는 것으로 확인되었다.

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□ 논문 및 저서

「Coracoclavicular stabilization using a suture button device for Neer type IIB lateral clavicle fractures」Journal of Shoulder and Elbow Surgery 26(5) 2017.

「Radiographic and clinical results of tension suture fixation using two washers with PHILOS plate for proximal humeral fractures」Injury 48 (2) 2017.

「Is the pectoralis major tendon a reliable reference for restoration of humeral length with fracture hemiarthroplasty?」Journal of Shoulder and Elbow Surgery 27(2) 2018.

「Biological aspect of pathophysiology for frozen shoulder」BioMed Research International 2018.

「Posteromedial elbow dislocations without relevant osseous lesions: clinical characteristics, soft-tissue injury patterns, treatments, and out-comes」Journal of Bone and Joint Surgery 100(23) 2018.

「Is the pectoralis major tendon a reliable reference for restoration of humeral length with fracture hemiarthroplasty?」 Journal of Shoulder and Elbow Surgery 27(2) 2019.

「Treatment strategy for frozen shoulder」 Clinics in Orthopedic Surgery 11(3) 2019.

「Is acromial fracture after reverse total shoulder arthroplasty a negligible complication?: A systematic review」 Clinics in Orthopedic Surgery 11(4) 2019.

「The incidence and risk factors of frozen shoulder in patients with breast cancer surgery」 The Breast Journal 26(4) 2020.

「Early clinical outcomes of manipulation under anesthesia for refractory adhesive capsulitis: Comparison with arthroscopic capsular release」 Clinics in Orthopedic Surgery 12(2) 2020.

「Recovery pattern after arthroscopic treatment for calcific tendinitis of the shoulder」 Orthopaedics & Traumatology: Surgery & Research 106(4) 2020.

「Protection of surgical team from COVID-19 during bipolar hemi-arthroplasty in an infected elderly patient」 Clinics in Orthopedic Surgery 12(3) 2020.

「Common extensor complex is a predictor to determine the stability in simple posterolateral elbow dislocation: Analysis of MR images of stable versus unstable dislocation」 Journal Clinical Medicine 9(10) 2020.

「Rapid destructive arthrosis due to subchondral insufficiency fracture of the shoulder: Clinical characteristics, radiographic appearances, and outcomes of treatment」 Diagnostics (Basel, Switzerland) 10(11) 2020.

「Revision arthroscopic bankart repair: A systematic review of clinical

outcomes」 Journal Clinical Medicine 9(11) 2020.

「Simultaneous bilateral acromial base fractures after staged reverse total shoulder arthroplasty: A case report」 World Journal of Clinical Cases 9(1) 2021.

「Chronicity is associated with the glenohumeral synovitis in patients with a rotator cuff tear」 Journal of Orthopaedic Research 12(6) 2020.

「Patients who have undergone rotator cuff repair experience around 75% functional recovery at 6 months after surgery」 Knee Surgery, Sports Traumatology, Arthroscopy 29(4) 2020.