Would non-anatomical fixation of coracoid bone block (Latarjet procedure) reproduce normal scapular kinematics?

In vivo three-dimensional dynamic comparison with contralateral healthy shoulders

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In vivo three-dimensional dynamic comparison with contralateral healthy shoulders

Directed by Professor Doo Sup Kim, Won Gil Cho

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감사의 글

본 논문이 완성되기까지 논문의 주제선정 및 실험 과정에

아낌없는 지도와 격려를 해 주신 김두섭 교수님께 감사의 말씀 드립니다.

의학적인 측면뿐 아니라 삶의 모든 면에서 본보기가 되어주셨습니다.

융합형 의과학자 양성 사업부터 지도교수를 역임해주시며 지지해주신 조원길

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은사님으로서 부족한 제자를 품어주시고 교육의 기회, 젊은 교수로서의 발판을

마련해주신 오진록 교수님께 감사드립니다.

본 논문의 심사에 참여해주시고 조언을 아끼지 않으신 김성훈 교수님, 손훈상

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실험 진행 단계에서 공이 큰 허형규 박사님에게 깊은 감사의 뜻을 표합니다.

이번 연구가 본 기관과 대구경북첨단의료산업진흥재단 첨단의료기기개발지원센터와

협력 연구의 발판이 될 수 있기를 기원해봅니다.

도움을 준 정형외과 김현우 선생님과 의국원들에게 감사의 말을 전합니다.

마지막으로, 조건 없는 애정으로 뒷받침해주신 존경스러운 아버지,

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사랑하는 나의 약혼녀 차지혜 양에게 이 논문을 바칩니다.

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ABSTRACT

Would non-anatomical fixation of coracoid bone block (Latarjet procedure) reproduce normal scapular kinematics?

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This study explores the Latarjet procedure to address shoulder instability, yet its impact on shoulder kinematics remains insufficiently studied. This controlled laboratory study aimed to analyze shoulder kinematics during active motions following the Latarjet procedure, hypothesizing that the nonanatomical transfer of the coracoid process would disrupt normal kinematics. Ten patients (age range, 20-52 years) undergoing the modified Latarjet procedure from June 2016 to November 2021 were included. Computed tomography and fluoroscopy generated 3-dimensional models of both shoulder joints, and a 3-dimensional–2-dimensional model-image registration technique assessed shoulder kinematics.

Scapular rotation parameters were compared during humeral abduction, and anteroposterior (AP) translation during active humeral external rotation. The

Latarjet side exhibited significantly increased scapular upward rotation at higher humeral elevations (130°, 140°, and 150°) compared to the nonsurgical side (P = 0.027). Posterior tilt, external rotation, and scapulohumeral rhythm showed no significant differences. AP translation at maximal humeral rotation revealed no significant disparity between Latarjet and nonsurgical sides (P = 0.28). Notably, on the Latarjet side, AP translation increased until 40° of humeral rotation (4.27 ± 4.64 mm) but decreased from 50°.

These findings suggest that the Latarjet procedure induces notable alterations in scapular upward rotation during maximal humeral elevation. However, most of the parameters (posterior tilt, external rotation, and scapulohumeral rhythm) showed no significant differences. While the observed posterior movement of the humeral head beyond 50° of rotation may represent an intended effect, the long-term implications, particularly the potential for osteoarthritis, warrant careful consideration. This study contributes to the understanding of the Latarjet procedure's impact on shoulder kinematics and underscores the importance of evaluating both short-term benefits and potential complications in the clinical application of this surgical intervention.

Key words : Latarjet; shoulder kinematics; scapulohumeral rhythm; 3D-2D model-image registration technique

1. INTRODUCTION

The Latarjet procedure is performed for patients with >25% of glenoid bone loss or off-track glenohumeral instability; its indication is becoming wider currently.[7,24] Its primary mechanism is understood as a dynamic sling effect of the conjoint tendon on the inferior two thirds of subscapularis, which plays important role in the anterior glenohumeral stability.[23]

This procedure replaces glenoid bone loss, but it has a nonanatomic “sling” effect on the conjoint tendon by transferring the coracoid process and reconstruction. Researchers have attempted to understand the process by which the mechanism would affect the 3D shoulder kinematics in actual patients under 3D dynamic settings.[11,23,25] Previous studies have demonstrated the dynamic sling effect of the conjoint tendon through cadaveric models by reporting on stability improvement in vitro.[5,11] Patel et al[20] evaluated the effects of the Latarjet procedure on glenohumeral kinematics in the setting of both glenoid and humeral Hill-Sachs lesion with cadaveric models.

However, cadaveric models have limitations in reproducing in vivo kinematic tension and load sharing of the anatomical shoulder joints. Di Giacomo et al[8] performed an in vivo static magnetic resonance imaging (MRI) study evaluating glenohumeral translation in the abduction and external rotation (ABER) position in patients with Latarjet procedure. Bey et al[2-4] measured 3D dynamics of the shoulder joint during active motion with their model-based tracking technique to compare the rotator cuff repair and control groups. Nonetheless, researchers have not performed an in vivo 3D dynamics evaluation of glenohumeral joint translation during active shoulder motion in patients undergoing the Latarjet procedure.

Our study was designed to assess the combined effects of the pathologic condition (traumatic instability) and Latarjet procedure on shoulder kinematics during active shoulder abduction and external rotation. I had hypothesized that the Latarjet procedure would affect normal shoulder kinematics because it involves a non-anatomical transfer of the bone block attached to various conjoined tendons to compress the subscapularis, which would result in alterations of dynamic muscular tension.[2] Thus, I aimed to compare the changes in scapular rotation during humeral abduction and humeral head anteroposterior (AP) translation in humeral external rotation.

2. METHODS

2.1. Participants

In this retrospective cohort study, I recruited patients who underwent the modified Latarjet procedure for unilateral traumatic recurrent instability at our institution from June 2016 to November 2021.[14,26] Patients with a history of shoulder surgery or injury other than dislocation and those with multidirectional instability, postoperative nerve injury or hardware loosening were excluded.

I included 10 men (age 20-52 years) who underwent the modified Latarjet procedure by a single surgeon using two bicortical 4.0-mm cannulated screws (DePuy Synthes®, Oberdorf Switzerland), with minimum follow up period of 1 year after the operation. All included patients achieved bony union on the surgical site and had no complications or limitations in the range of motion, with good Constant-Murley scores (>85 out of 100). Two patients were affected on the right side, and eight were affected on the left side. Four patients were affected on the dominant side (two right, two left), and six patients were affected on the non-dominant side (all left). All of the included patients provided written informed consent after obtaining a comprehensive explanation of the purpose of our study. The protocol of this study was approved by the institutional review board of our institution.

2.2. Surgical Technique

The patients were placed in the modified beach-chair position. Incisions were made using the deltopectoral approach. The anterior coracoacromial ligament and pectoralis minor were released from the coracoid process. The surgeon attempted to harvest the largest coracoid block, up to 20 mm; however, at least 17 mm of the bone blocks were harvested because of the smaller size of bone blocks in Asians, allowing the fixation using two screws. The harvested coracoid bone blocks were fixed onto the 3 to 6 o'clock position of the glenoid rim after splitting the subscapularis and performing capsulotomy. After firm fixation with two bicortical 4.0-mm cannulated screws (DePuy Synthes®, Oberdorf, Switzerland), the capsule was repaired.

2.3. Image Acquisition and 3D Reconstruction

Preoperative MRI and computed tomography (CT) (SOMATOM Sensation 16; Siemens Medical Solutions, Malvern, PA, USA) scans were captured, and postoperative CT scans were captured at 3 months postoperatively as a routine outpatient clinic evaluation. At 1 year postoperatively, fluoroscopic radiographs (Infinix Active; Toshiba, Tochigi, Japan) of the shoulder in humeral abduction and in external rotation were captured sequentially in two planes on each side of the shoulder for motion-related 3D dynamics evaluation of shoulder kinematics.

For the fluoroscopic radiographs, patients were in a sitting position with their torso 30° to the plane to align the scapula perpendicular to the x-ray beam; images were obtained at 10 frames per second. First, the patients were instructed to perform scapular plane abduction to the maximum tolerable angle with their palms facing forward, the thumb pointing up, and the elbow joint extended completely. I rehearsed the rate of arm movements in every patient and calculated the total number of the collected shots after each movement. The x-ray beam was shot perpendicular to the coronal plane. One cycle was defined as the arm abduction from 0° to the maximum tolerable degrees and took approximately 2 to 3 seconds. Second, I instructed the patients to externally rotate the arm in the frontal plane with the elbow at 90° of flexion and the shoulder abducted to 90° (the 90-90 position). The x-ray beam was shot perpendicular to the axial plane. All the patients rotated their arm from the initial position to the maximum angle for approximately 2 to 3 seconds per cycle. Each patient performed a single cycle of the fluoroscopic procedure for both sides of the shoulder. They abducted and rotated their arm to the maximal tolerated angle, and no patient displayed a limited range of motion on gross examination. Because real-time angle measurement is impossible during the fluoroscopic shoots, numerous values obtained from various angles were again fit to the polynomial curve; interpolation was performed to obtain the exact value at the desired angles.

The CT scans of the bilateral shoulders were performed with a 1-mm slice pitch (image matrix, 512 × 512; pixel size, 0.9765625 × 0.9765625 mm). The CT images were segmented, and 3D models of the humerus, scapula, and clavicle were constructed using ITK-SNAP (Penn Image Computing and Science Laboratory, Philadelphia, PA, USA) (Figure 1). X-, Y-, and Z-axes were applied to the 3D reconstructed model using the anatomic coordinate system (Geomagic Studio, Morrisville, NC, USA).[13,18] The humeral origin was at the centroid of the humeral head. The Y-axis was the longitudinal shaft axis, the Z-axis was the line penetrating bicipital groove, and the X-axis was a line perpendicular to the plane formed by the Y- and Z-axes. The scapular origin was set at the midpoint between the most superior and inferior bony edges of the glenoid; the Y-axis pointed superiorly and the Z-axis pointed anteriorly from the origin (Figure 2).

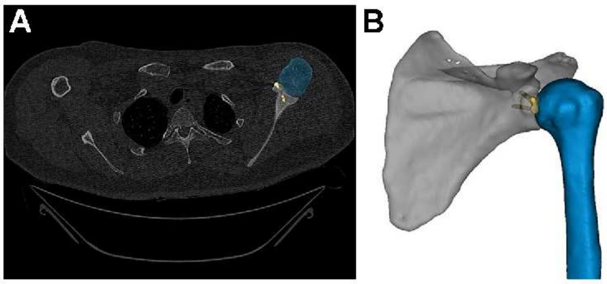

Figure 1. Using computed tomography axial images, 3D models of the scapula and humerus are constructed.

(A) Axial image, (B) reconstructed 3D models; note gray shaded scapula, blue shaded humerus, gold shaded screw

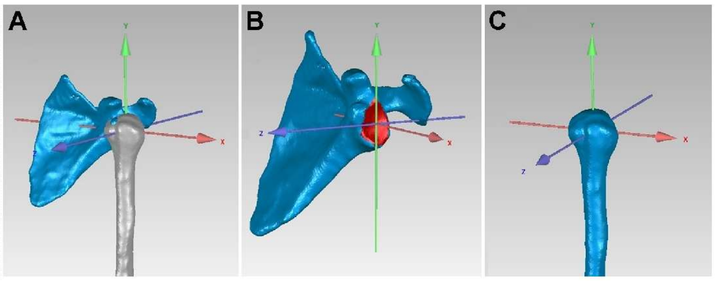

Figure 2. Three-dimensional models of the (A) shoulder joint, (B) glenoid, and (C) humerus. Upon reconstruction, the anatomic coordinates were applied with Geomagic studio. Red line = X-axis; green line = Y-axis; and purple line = Z-axis.

2.4. 3D-2D Model-Image Registration

The 3D models with anatomic coordinates were registered to the 2D fluoroscopic images using Joint-Tract, an open source software program (www.sourceforge.net/projects/jointtrack).[15-17,22] Similar 3D model/2D image registration techniques have been discussed previously.[1] The size and orientation of the 3D reconstructed models were fit to the 2D fluoroscopic images. 3D models were contructed for the registration of a fluoroscopic image series (Figure 3). A similar concept of single-plane 3D shape registration was described previously in natural shoulder joints, and the precision of this technique was confirmed as being 0.53 mm for in-plane translation, 1.6 mm for out-of-plane translation, and 0.54° for rotations.[6,16]

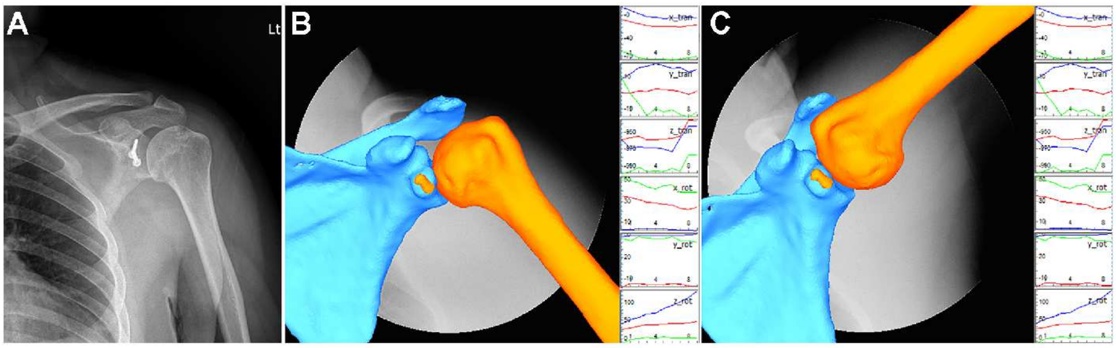

Figure 3. Three-dimensional (3D) models with coordinates are encoded on 2-dimensional (2D) fluoroscopic images with the 3D-2D model-image registration technique. (A) Clinical radiograph of a left shoulder after undergoing the Latarjet procedure, and the corresponding model with applied fluoroscopic image at (B) the resting position with their palms facing forward, the thumb pointing up, and the elbow joint extended completely and (C) maximal abduction.

The humeral and scapular kinematics in the radiographic coordinate system were analyzed using Euler and Cardan angles.[12] Humeral abduction was defined as the degree of rotation in the Z-axis, and humeral external rotation defined as the degree of rotation in the Y-axis. Regarding scapular motion, the anterior-posterior tilt denoted the rotation in the X-axis, internal-external rotation denoted the rotation in the Y-axis, and upward-downward rotation denoted the rotation in the Z-axis. The AP translation of the humeral head center was defined relative to the Z-axis of the center of the scapula (Figure 2).

2.5. Data Extraction

I calculated humeral abduction as the independent variable for scapular rotation parameters (including upward rotation, posterior tilt, external rotation, and scapulohumeral rhythm), and humeral external rotation as the independent variable for the relative AP translation of the humeral head with scapula. MATLAB code (MathWorks Inc., Natick, MA, USA) was used to extract the values of shoulder kinematics in every 10° increment of humeral abduction and external rotation, and polynomial curve fitting and interpolation were performed to analyze the expected data at specific 10° increments of the independent variables.

Scapulohumeral rhythm (SHR) was calculated as $(\Delta_H - \Delta_S)/\Delta_S = 1/(\Delta_S/\Delta_H) - 1$,[16] where Δ_H indicates changes in the humeral abduction angle and Δ_S represents changes in the scapular upward rotation angle. Polynomial curve fitting was previously performed for humeral abduction and scapular upward rotation in the data interpolation stage. Subsequently, Δ_S/Δ_H was calculated with differentials of the function expression. The humeral abduction angle was the independent value for SHR. Thus, I calculated the SHR for both sides of the shoulder with

10° increments of humeral abduction.

2.6. Statistical Analysis

The changes in scapular rotation during humeral abduction and in humeral head AP translation during humeral external rotation were compared between the Latarjet and nonsurgical shoulders using two-way repeated-measures analysis of variance. The initial values for scapular rotation (measured in degrees) and humeral head AP translation (measured in millimeters) were reset to zero when the humeral abduction or external rotation values were zero. This approach helped to minimize errors derived from varying scapular orientations and locations among the patients. A post hoc Bonferroni-corrected *t* test was performed upon detecting a significant difference. *P* values of <0.05 were considered statistically significant.

3. RESULTS

Figure 4 depicts the values of scapular upward rotation, posterior tilt, external rotation, and SHR along the humeral elevation degrees in humeral abduction. Figure 5 depicts the values of AP translation of the humeral head along the external degrees of rotation of the humerus.

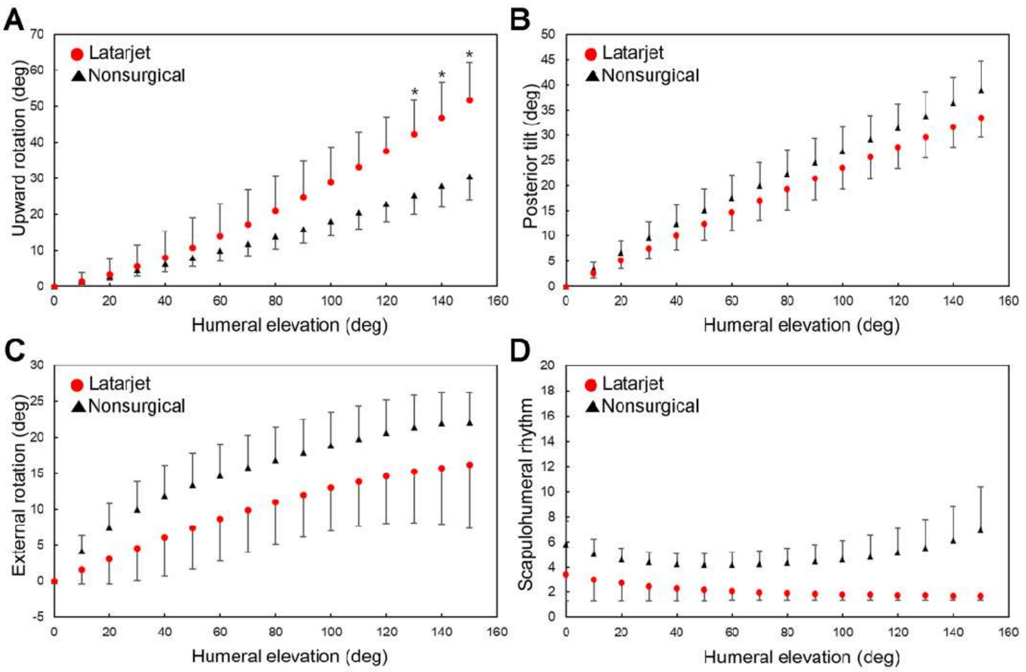

Figure 4. Comparison between the Latarjet and nonsurgical sides of scapular rotation parameters according to humeral abduction. (A) Scapular upward rotation, (B) Scapular posterior tilt, (C) Scapular external rotation, and (D) Scapulohumeral rhythm. Error bars indicate standard deviation *Statistically significant difference between sides ($P < .05$).

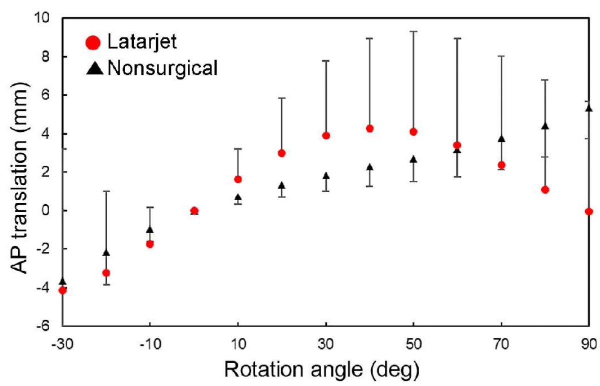

Figure 5. Comparison between the Latarjet and nonsurgical sides of humeral

anteroposterior (AP) translation relative to the glenoid center according to humeral external rotation. Error bars indicate standard deviation

3.1. Scapular Upward Rotation

In both groups, scapular upward rotation increased with humeral elevation. Interestingly, the overall changes of scapular upward rotation were higher on the Latarjet side; but only at the maximal degrees of humeral elevation (at 130°, 140°, and 150°) were significant. The values of scapular upward rotation at 150° of humeral elevation were 51.74° ± 10.54° and 30.51° ± 6.46° for the Latarjet and nonsurgical sides, respectively (P = 0.027) (Figure 4A).

3.2. Scapular Posterior Tilt

The scapular posterior tilt values increased in both groups with the humeral elevation degrees. The Latarjet sides displayed lower values of scapular posterior tilt than the nonsurgical side; however, the difference was nonsignificant. The values of scapular posterior tilt at 150° of humeral elevation was 33.54° ± 3.93° and 39.1° ± 5.64° for the Latarjet and nonsurgical sides, respectively (P = 0.291) (Figure 4B).

3.3. Scapular External Rotation

The scapular external rotation degrees increased in both groups as well in proportion to the humeral elevation angles. The Latarjet sides displayed overall limitation of the scapular external rotation than the nonsurgical side; however, the difference was insignificant. The values of scapular external rotation at 150° of humeral elevation was 16.15° ± 8.76° and 22.0° ± 4.2° for the Latarjet and nonsurgical sides, respectively (P = 0.48) (Figure 4C).

3.4. Scapulohumeral Rhythm

The slope of the upward rotation of scapula (Δ_S/Δ_H) increased more on the Latarjet side with humeral elevation; simultaneously, SHR ($1/(\Delta_S/\Delta_H) - 1$) displayed decreasing values for the Latarjet side. The difference of values in SHR between the Latarjet and nonsurgical sides increased with humeral elevation; however, it was nonsignificant. The values of SHR at 150° of humeral elevation was 1.71 ± 0.36 and 6.93 ± 3.39 for the Latarjet and nonsurgical sides, respectively (P = 0.14) (Figure 4D).

3.5. AP Translation of the Humeral Head

With the forearm facing straight forward in 90-90 position defined as 0° Y-axis rotation of humerus, we calculated AP translation beginning from 30° internal rotation (−30°) to the maximal external rotation (90°) of the humerus, which ended at the maximal external rotation ABER position. The humeral head translated anteriorly with an increase in the humerus rotation on the nonsurgical side. Interestingly, on the Latarjet side, AP translation increased until 40° of humeral rotation (4.27 ± 4.64 mm) but began to decrease from 50° of rotation. There were no significant differences in AP translation at any angle of humeral rotation. However, at the maximal rotation of humerus, the AP translation values were −0.06 ± 5.73 mm and 5.33 ± 1.60 mm in the Latarjet and nonsurgical sides, respectively (P = 0.28) (Figure 5).

4. DISCUSSION

Researchers have attempted to understand the stabilization mechanism underlying the Latarjet procedures. Wellmann et al[24] stated that belt-suspension stabilization by the conjoint tendons and subscapularis tendon is central to the ABER position and that the transferred CAL with capsule reconstruction is crucial in abduction and neutral rotation. Studies have proven the normalization of articular contact pressures of the glenohumeral joint and the sling effect of the coracobrachialis crossing the subscapularis.[10] Yamamoto et al[25] stated that the sling effect is the primary contributor of stability and the percentage of effect increases with the range of motion. Patel et al[20] measured the upper limit of the Latarjet procedure with combined defects of the glenoid bone loss, with humeral head bone defect in cadaveric models; they stated that coracoid transfer itself would not suffice the instability in case of >31% humeral head bone loss. The stability gained after the Latarjet procedure does not solely depend on the bony structure augmentation itself, rather than more on the musculocutaneous component (sling effect of the conjoint tendon and subscapularis).

The kinematic tension must be re-created to evaluate the actual effect of the muscular component of the Latarjet procedure. Despite several attempts to reproduce the dynamic component in elaborate settings with cadaveric models[5, 11, 20, 25], re-creating physiologic muscle tension and proprioception was unsuccessful. Researchers have reported on the disharmony of the glenohumeral translational results between in vivo and in vitro studies.[8] Thus, dynamic in vivo evaluation of the shoulder kinematics is crucial; however, technical impalpability is the primary issue because of the challenging motion-related dynamic CT scan.

Di Giacomo et al[8] evaluated glenohumeral translation with in vivo MRI setting in the ABER position in patients who underwent the Latarjet procedure. They understood the limitations of the in vitro study and have performed elaborate work to recreate the in vivo dynamic contraction in the ABER position. Nonetheless, the patients' position was static during the MRI scan; whereas it represents the end critical position in the evaluation of glenohumeral stability, it does not reproduce the dynamic shoulder kinematics while the patients elevate their arm from 0° to the maximal degrees in real time. I can gain the fluoroscopic view while the patients abduct and rotate their arm on both sides, thus highlighting whether the 2D images can be converted to 3D images for dynamic kinematics evaluation. Matsuki et al[16] performed a novel research using biplane and monoplane fluoroscopes to address scapular asymmetry by analyzing dynamic scapular rotations using a 3D-2D registration technique.

In our study, most shoulder kinematics of the Latarjet and nonsurgical sides did not display a significant difference. This finding could be attributed to our small sample size. However, upward rotation of the scapula displayed significantly higher values at maximal humeral elevation degrees. One can assume that, since the maximal humeral abduction in daily activities are rare, Latarjet procedure does not significantly affect the patients' shoulder kinematics of daily activities. The exact mechanism of the Latarjet procedure is not understood; nonetheless, the dynamic sling effect of conjoint tendon on subscapularis may have played a significant role. However, the trapezius, rhomboids, and serratus anterior muscles are not expected to be directly affected by the Latarjet procedure. Consequently, alterations in scapular mechanics are more likely to result from the decreased GH motion and loss of the pectoralis minor antagonist.

Study results indicated that AP translation of the humeral head decreased with >50° increase in humeral rotation, suggesting the head began to move posteriorly. The ABER position makes the humeral head move anteriorly and is the critical position for anterior instability of shoulder. Because of the sling effect, the Latarjet procedure may affect normal physiology and prevent anterior dislocation, which was the desired result. However, this phenomenon can cause more pressure on the posterior glenohumeral joint and may generate glenohumeral osteoarthritis in the long term.[9] Furthermore decreased external rotation and posterior tilt of the scapula could lead to subacromial impingement. In addition, increased posterior translation will increase internal impingement and posterior labrum pathology. Taken together, I can discuss the potential for increasing the sample size and extending the follow-up period to guide the direction of future studies. Longer term follow-up of Latarjet patients is needed to see if these theoretical concerns actually occur clinically.

4.1. Limitations

This study has some limitations. I could not perform dynamic evaluation for patients with glenohumeral instability in pre-surgical condition; thus, it is difficult to determine whether the kinematic differences seen were a result of the pathology itself on the surgically reconstructed side. Thus, the reported values may not have been solely derived from the effects of the surgical procedure. Moreover, the limited number of cases could affect the significance of our results. Thus, the study may be underpowered to detect some differences because of the small sample size. In our center, Latarjet procedures are less commonly performed than Bankart repairs and are usually reserved for patients with some severe glenohumeral instability; patient recruitment was also affected because of the coronavirus 2019 pandemic. Multi-center-based studies sharing similar dynamic evaluation protocol could be beneficial in the future. In addition, our findings did not reflect dynamic positioning of the patients during the fluoroscopic procedure and differences of the anatomical orientation of the scapula. To minimize the error, the patients were instructed to sit with torso 30° to the plane and maintain the position. Radiation hazard can be another issue for patients undergoing fluoroscopy for both shoulders. I could not include other sets of shoulder movements, such as horizontal extension (i.e., the apprehension position) because of these problems. I conducted each cycle one time, for approximately 2 to 3 seconds so as to minimize the radiation exposure. This 3D-2D matching technique has merits over other dynamic motion analysis, which can prevent skin slippage. I hypothesized that the differences in scapular rotation and relative humeral translation to the glenoid attributes principally to anatomical differences rather than the effect of dynamic muscular tension with 0° degrees of the humeral ABER position, which implies the neutral position. The attempts to confirm the difference at resting position as well as at presurgical condition could reveal the effects of specific components in the future.

5. CONCLUSION

This study evaluated dynamic shoulder kinematics of the patients who had undergone the Latarjet procedure during active shoulder abduction using the 3D-2D model registration technique. The Latarjet side demonstrated significant changes in scapular upward rotation during maximal humeral elevation, compared with the contralateral nonsurgical shoulder. Posterior tilt, external rotation and scapulohumeral rhythm were not significantly different. Posterior movement of the humeral head at over 50° of humeral rotations could be the desired effect; however, researchers should evaluate the long-term complications, such as osteoarthritis or subacromial impingement and see if these theoretical concerns occur actually. Plus, It would be beneficial to determine the true kinematic effect of the surgery itself excluding the pathologic presurgical condition if possible.

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국 문 요 약

비해부학적 오구돌기 고정술(라타젯 술기)이 정상적인 견갑골 운동학적 움직임을 재현할 수 있는가?

건측 견갑골과의 3차원적 역동적 체내 비교 연구

본 연구는 견관절 불안정성을 교정하기 위한 술식인 라타젯 술식이 견관절 운동학에 미치는 영향에 대해 비교 분석하였다. 대조 실험 연구를 통해 환자가 역동적으로 움직이는 동안의 운동학을 분석하였으며, 본 저자는 오구돌기의 비해부학적 전이술이 정상 견관절 운동학에 영향을 미칠 것이라 가정하였다. 2016년 6월부터 2021년 11월까지 라타젯 술식을 받은 10명의 남성(20-52세)을 포함시켜 건측과 환측을 비교하였다. CT를 촬영하여 3D 모델을 구성하고, 연속촬영을 한 2D 사진에 3D-2D model-image registration technique을 이용해 3D 모델을 등록하여 견관절 운동학을 분석하였다.

상완골을 외전하는 동안 겹갑골의 회전 변수들이 분석되었고, 상완골을 외회전 하는 동안 견갑골에 대한 상완골의 상대적인 전후방 이동을 분석하였다. 상완골을 최대치로 외전했을 때 (130°, 140°, and 150°) 라타젯 술식을 시행한 측에서 건측에 비해 유의하게 상방 회전이 증가하였다 (P = 0.027). 후방경사, 외회전, 그리고 견갑상완리듬은 건측과 환측의 유의한 차이를 보이지 않았다. 전후방 이동 역시 상완골의 최대 외회전 시에도 건측과 환측에서 유의한 차이를 보이지 않았다 (P = 0.28). 라타젯을 시행한 측에서 상완골 외회전

40°까지는 상완골두가 견갑골에 비해 (4.27 ± 4.64 mm) 전방으로 이동하였으나 50° 이상의 외회전부터 상완골두의 후방 움직임이 관찰되었다.

상완골의 최대 외전 시에 라타젯 측과 건측 견갑골 상방회전의 유의한 차이가 관찰되었다. 후방경사, 외회전, 견갑상완리듬에선 건측과 환측의 유의한 차이가 관찰되지 않았다. 50° 이상의 상완골 외회전 시에 상완골두가 후방으로 이동하는 것은 전방 불안정성 치료에서 기대되는 효과이나 골관절염과 같은 장기적인 합병증에 대한 추후 연구가 필요하다. 본 연구는 라타젯 술식이 견관절 운동학에 미치는 효과를 분석하였으며, 장기적인 합병증과 임상적 적용 효과에 대한 가이드를 제시하였다.

핵심되는 말 : 라타젯(오구돌기 전이술); 견관절 운동학; 견갑상완리듬; 3D-2D model-image registration technique