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The Biomechanics of the Latarjet Reconstruction: Is It All About the Sling?

Nobuyuki Yamamoto, MD,* and Scott P. Steinmann, MD†

It has been clinically believed that the stabilizing mechanism of the Latarjet procedure is the sling effect. Biomechanical studies have demonstrated that there are 3 stabilizing mechanisms of the Latarjet procedure, the main one being the sling effect produced by the subscapularis and conjoint tendons. The other 2 mechanisms are the suturing of the capsular flap at the end-range arm position and reconstruction of the glenoid concavity at the mid-range arm position. All 3 stabilizing mechanisms function at both the mid- and end-range arm positions. After the Latarjet procedure, the shoulder even with a large glenoid defect can have stability increased by 14% compared to the normal shoulder. The acceptable clinical outcomes of the Latarjet procedure are supported by these 3 stabilizing mechanisms.
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Why Good Clinical Results Can Be Obtained Without the Bankart Repair?

The Latarjet procedure has gained popularity with recent reports[1,2] showing that postoperative arthritis can be avoided by appropriate positioning of the coracoid bone graft. Excellent clinical results even for shoulders with a large glenoid defect have been reported. Surgical procedures for treating anterior shoulder instability can be divided into 2 groups: intra-articular and extra-articular. The Latarjet procedure is included in extra-articular techniques, and the Bankart repair is included in intra-articular stabilizing procedures. Although a Bankart lesion itself is not repaired in the original Latarjet procedure or in most of the modified Latarjet procedures, excellent clinical outcomes have been reported.[3-5] A Bankart lesion is known to be an essential lesion in patients with anterior shoulder instability. Surgeons have asked why good clinical results can be obtained by the Latarjet procedure in which the essential lesion, the Bankart lesion is not repaired? To date, "sling effect of the subscapularis muscle" has been clinically believed as the main stabilizing mechanism of this procedure. This was speculation among surgeons. Its precise stabilizing mechanism had not been studied.

*Department of Orthopaedic Surgery, Tohoku University School of Medicine, Sendai , Japan.
†Department of Orthopedic Surgery, Mayo Clinic, Rochester, MN.
Investigation performed at the Mayo Clinic, Rochester, Minnesota.
Address reprint request to Scott P. Steinmann MD, Department of Orthopedic Surgery, Mayo Clinic College of Medicine, 200 First Street SW, Rochester, MN 55905. E-mail: steinmann.scott@mayo.edu

Biomechanical Experiments Using Cadaveric Shoulders

Stability in the Mid- and End-Range Arm Positions

It is biomechanically known that shoulder stability depends on arm position. The main stabilizer of the shoulder joint is the capsuloligamentous tissues in the end-range arm position (abduction and maximum external rotation) (Fig. 1A, B) and the concavity compression effect by the rotator cuff muscles in the mid-range arm position (the other arm positions). That is why it is important to simulate 2 arm positions in research studies: 60° of abduction relative to the scapula and maximum external rotation and neutral rotation to clarify the stabilizing mechanisms in all range of motions.

Subjects and Methods

Fresh-frozen cadaveric shoulders were used. A custom multi-axis electromechanical testing machine with a 3-degrees-

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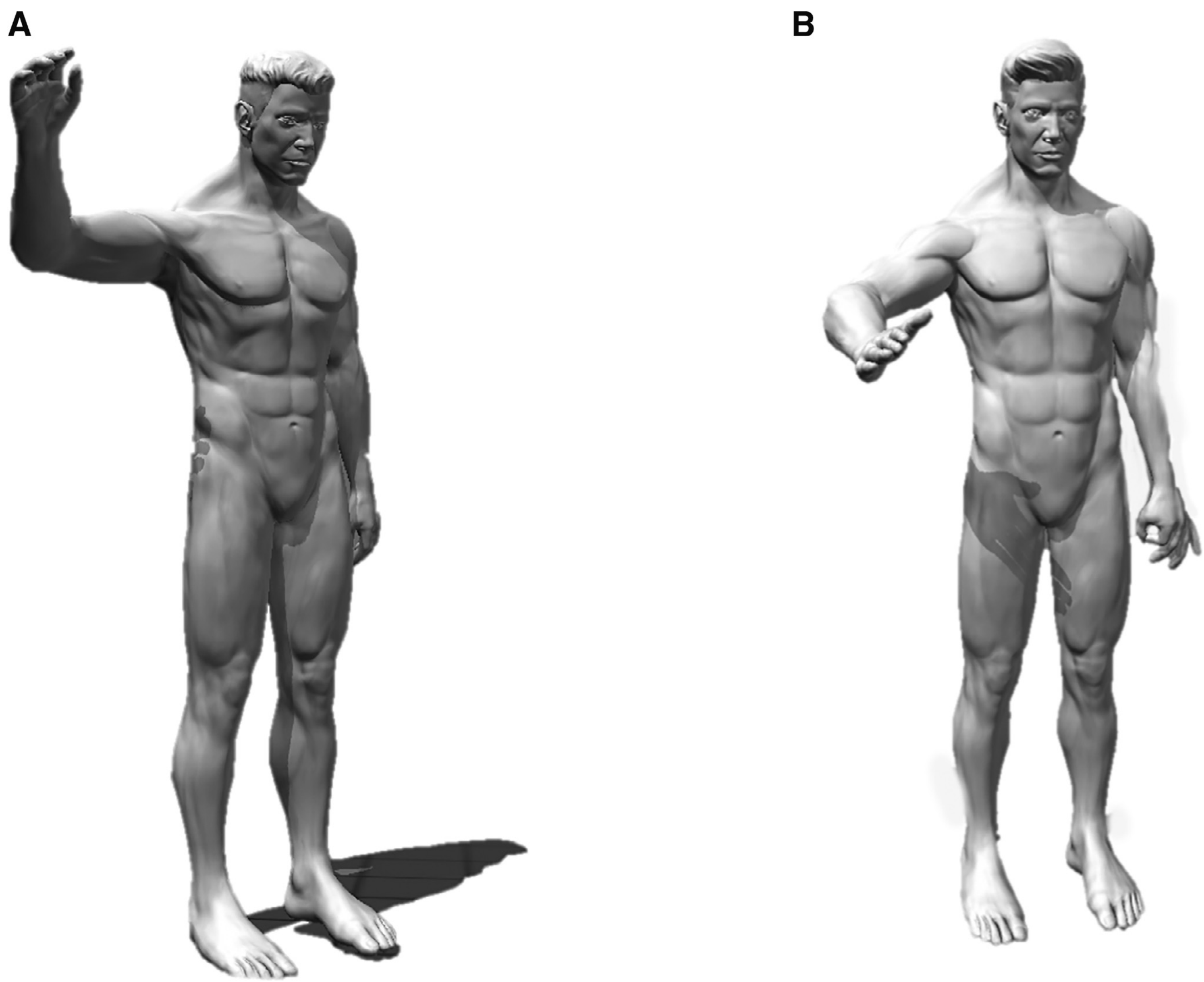

Figure 1 Two arm positions. Shoulder stability depends on the arm position: the capsuloligamentous tissues in the end-range arm position (A) and the concavity compression effect by the rotator cuff muscles in the mid-range arm position (B).

of-freedom load-cell was utilized (Fig. 2). With a 50-N axial force, the humeral head was translated in the anterior direction, and the peak translational force was measured. Three sets of loads were applied to see the relationship between the loading on muscles: (10 N, 2.5 N), (20 N, 5 N), and (30 N, 7.5 N) applied to the subscapularis and conjoint tendon, respectively. A large glenoid defect (25% of glenoid width) was created.

Surgical Technique

There are many variations of the Latarjet procedure. We followed Walch's surgical technique[1] in this study. The subscapularis muscle was divided at the junction of the superior two-thirds. A small anterior capsulotomy (1.5 cm) was performed. The bone block was positioned flush to the anterior-inferior margin of the glenoid at 4 o'clock. Two AO 4.5-mm malleolar screws driven into the posterior cortex secured the coracoid process (CP) to the glenoid. The Bankart repair was not performed.

Part I Study

Few biomechanical studies[6] have demonstrated the stabilizing mechanism of Latarjet procedures. To clarify the experimental steps, we divided the study into 2 experimental parts. In the first experiment,[7] we tried to clarify the main stabilizing mechanism and the contribution of the subscapularis and conjoint tendons. Specimens were divided into 2 groups (A and B) according to the order of removing the subscapularis and conjoint tendons because it was expected that this order might affect the results. In the group A, the conjoint tendon was removed following removal of the subscapularis tendon. In the group B, first, the conjoint tendon was removed.

The main stabilizing mechanism of the Latarjet procedure was demonstrated to be the sling effect produced by the subscapularis and conjoint tendons at both the end-range and the mid-range arm positions. After removing either the subscapularis or conjoint tendon, the force significantly decreased. However, there were no significant differences

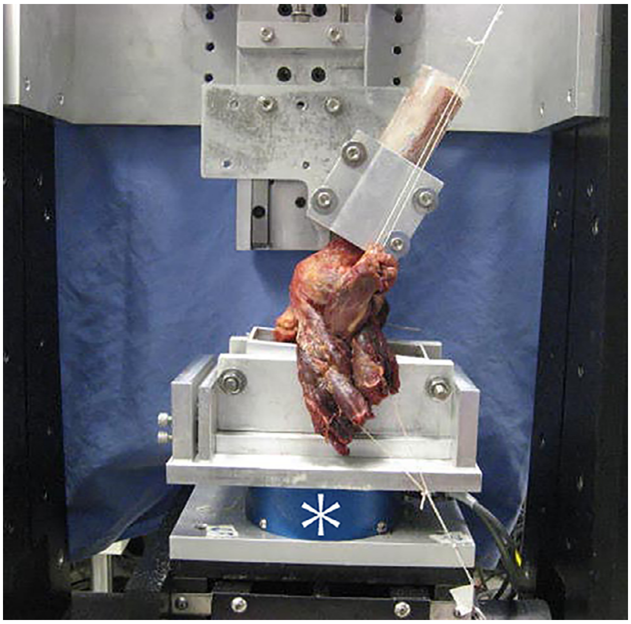

Figure 2 A custom multiaxis electromechanical testing machine A 6-degrees-of-freedom load-cell is indicated as * in the photo.

between 2 groups. It was concluded that the 2 tendons contributed to stability equally.

Part II Study

In the Part I study, small capsulotomy and bone exposure to transfer the CP, which are performed in real surgery, were not simulated. In the Part II study,[8] we further investigated the effect of suturing the lateral capsular flap to the stump of the coracoacromial ligament (CAL) which is a common addition to the Latarjet technique (Fig. 3). The peak translational force was measured (1) with the intact capsule, (2) with a Bankart lesion, and (3) after the Latarjet procedure with the

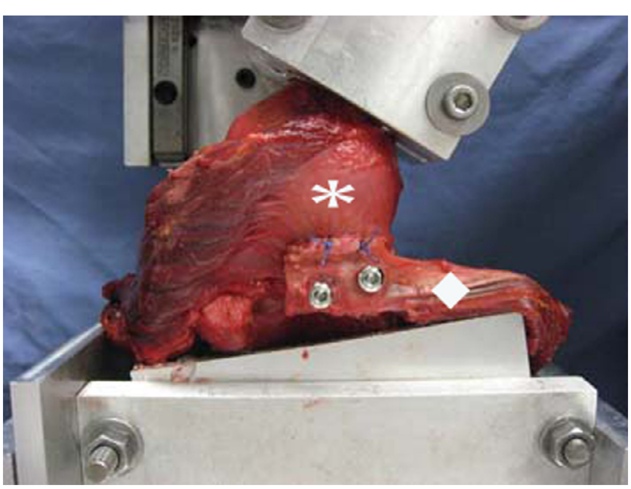

Figure 3 Latarjet procedure with the capsule reattached to the coracoacromial ligament. The lateral capsular flap (*) was sutured to the stump of the coracoacromial ligament. Two AO 4.5-mm malleolar screws secured the coracoid process with the conjoint tendon (◇) to the glenoid. The subscapularis muscle was elevated in this photo.

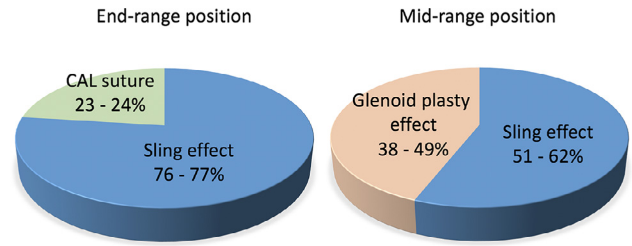

Figure 4 The stabilizing mechanism of the Latarjet procedure. At the end-range arm position, 76%-77% of the stability was contributed by the sling effect and the remaining 23%-24% by the suturing of the coracoacromial ligament. In the midrange arm position, the contribution of the sling effect was 51%-62%. Reconstruction of the glenoid concavity contributed the remaining 38%-49%. CAL suture, suturing the coracoacromial ligament (capsular flap); glenoid plasty effect, reconstruction of the glenoid concavity.

capsule reattached to the CAL. The 2 tendons were then removed to see the contribution of the sling effect to stability, and the sutures of the capsular flap to the CAL were removed to see its contribution.

At the end-range arm position, 76%-77% of the stability was contributed to the sling effect (Fig. 4). The remaining 23%-24% was contributed to the suturing of the CAL (suture effect). In the mid-range arm position, the contribution of the sling effect was 51%-62%. Reconstruction of the glenoid concavity contributed the remaining 38%-49% (glenoid plasty effect). The shoulder with a large glenoid defect became stable and stability increased by 14% compared to the normal shoulder after the Latarjet procedure. Stability increased significantly with increases in the load applied to the subscapularis and conjoint tendons at the mid-range arm position. This means that if the muscle strength of the subscapularis and conjoint tendons increases, the shoulder becomes more stable at the mid-range arm position. This might benefit contact or collision athletes who need stability in the mid-range arm position during athletic contests.

What Is the Sling Effect?

The sling effect was demonstrated to be the main stabilizing mechanism of the Latarjet procedure. Results showed that the sling effect was provided by both the subscapularis and conjoint tendons. The split subscapularis tendon provided muscle stability because the intersection of the transferred conjoint tendon added tension to the inferior portion of the subscapularis (Fig. 5). At the end-range arm position, the intersection of the 2 tendons became taut together in front of the humeral head. Observation by ultrasound elastography revealed that the intersection of the subscapularis and conjoint tendons became stiffer with the arm in external rotation compared to that with the arm in internal rotation (Fig. 6A, B).

For these reasons, the shoulder becomes stable after the Latarjet procedure even though a Bankart lesion is not repaired. Stability increased with load at the mid-range arm

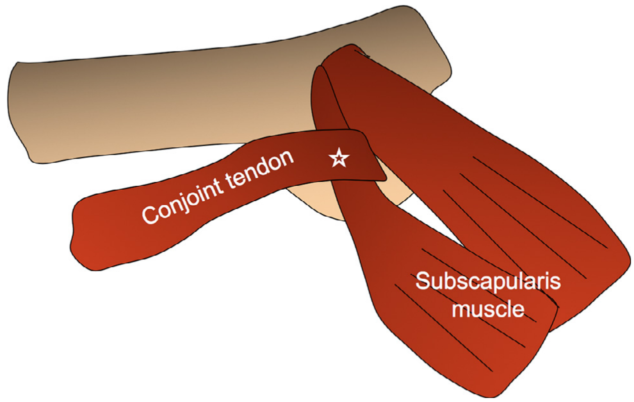

Figure 5 Schematic illustration of the sling effect. The sling effect was provided by the subscapularis and conjoint tendons. The split subscapularis tendon provided muscle stability, working as a barrier because the intersection (☆) of the conjoint tendon added tension to the inferior portion of the subscapularis.

position. It has been reported by various authors that dynamic stability depends on the muscle contraction force in the mid-range arm position.[9-11] This finding explains why the sling effect works most effectively in the mid-range arm position, at which the force of muscle contraction is related to the stability of the joint.

Which Is More Important, Conjoint or Subscapularis Tendon?

In our studies, specimens were divided into 2 groups according to the order of removing the subscapularis and conjoint tendons. After removing either the subscapularis or conjoint tendon, the peak translational force significantly decreased. However, there were no significant differences between 2 groups. This means both 2 tendons contributed to stability equally. Surgeons have believed that the subscapularis tendon is important for the sling effect but our results indicated that both of them are necessary so that the intersection of 2 tendons works as a stabilizer. If the subscapularis or conjoint tendon is dysfunctional for some reason, one cannot expect the sling effect to be reproduced by these 2 tendons.

Contribution of the Sutures of the Capsular Flap to the CAL

The contribution of the sutures of the capsular flap to the CAL to the stability was 19%-20% as the load changed at the end-range position, whereas the sutures to the CAL did not contribute to the stability at the mid-range position. Some

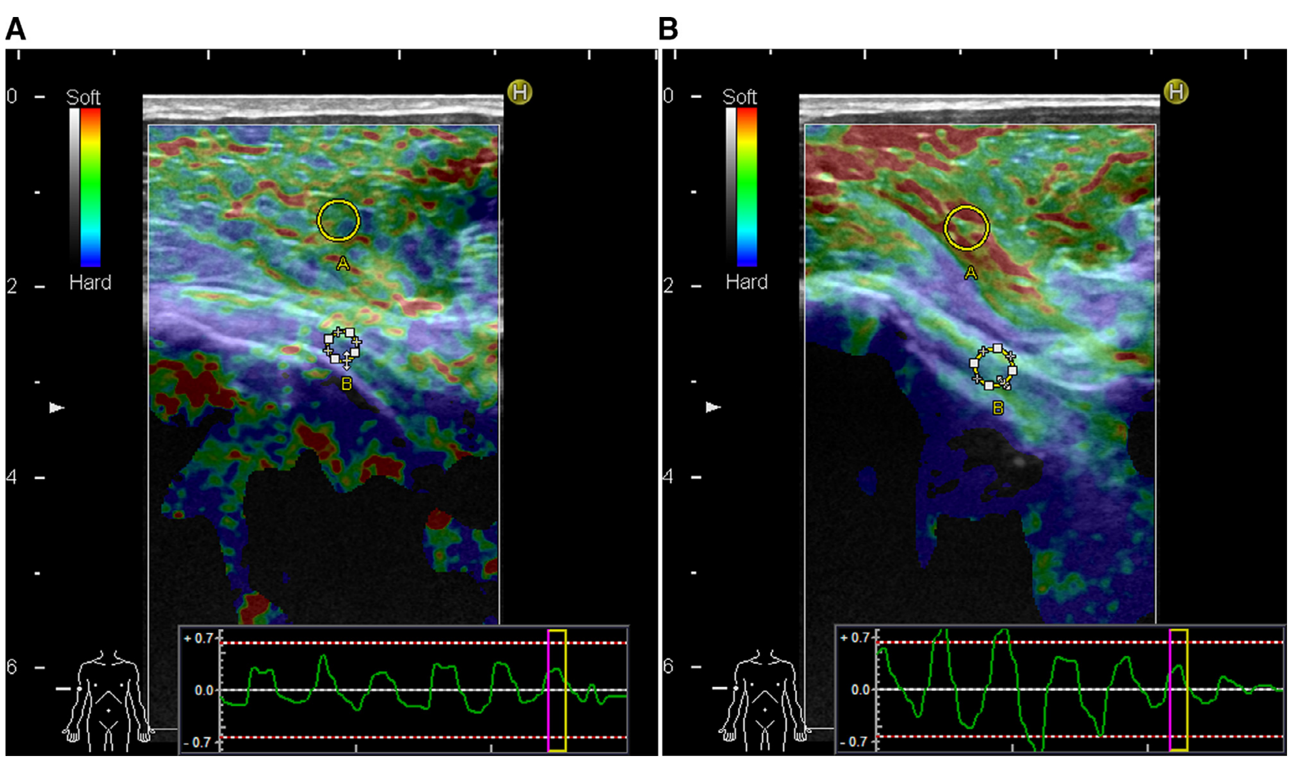

Figure 6 Observation of the sling effect by ultrasound elastography. Softer tissue is colored red and harder tissue blue in the ultrasound elastography image. (A) With the arm in internal rotation, the intersection he subscapularis and conjoint tendons (circle B) showed yellow. (B) With the arm in external rotation, the intersection he subscapularis and conjoint tendons (circle B) showed blue. (Color version of figure is available online.)

surgeons do not suture the capsular flap to the CAL. However, by adding sutures of the capsular flap, a 19%-20% increase in stability is expected at the end-range position. Thus, we recommend that the capsular flap be sutured to the CAL when performing the Latarjet procedure.

"Triple Locking"

At the end-range arm position, 76%-77% of the stability was contributed to the sling effect. The remaining 23%-24% was contributed to the suturing of the CAL. In the mid-range arm position, the contribution of the sling effect was 51%-62%. Reconstruction of the glenoid concavity contributed the remaining 38%-49%. These 3 are the stabilizing mechanisms of the Latarjet procedure. Interestingly, the concept of "triple locking" proposed by Patte[12] (often now referred to as "triple blocking"), which includes repair of the capsule (capsular locking), preservation of the lower one-third of the subscapularis (tendinomuscular locking), and extension of the osseous glenoid concavity (osseous locking), is consistent with our laboratory results. In our studies, capsular locking is equal to CAL suturing effect, and tendinomuscular locking is the same as sling effect. Osseous locking is the glenoid plasty effect. Thus, our biomechanical studies clarified the same stability mechanisms which Patte[12] clinically proposed.

Surgical Indication for Latarjet Procedure

Based on our biomechanical studies, we are able to comment on the indications for the Latarjet procedure. Surgical indications would include: (1) shoulders with a large glenoid defect (greater than 25% of the glenoid width), (2) shoulders with a large Hill-Sachs lesion (off-track lesion[13]), (3) contact or collision athletes, (4) shoulders with tears on the capsule, and (5) revision Bankart repairs. In our study, the shoulder with a large glenoid defect became stable and stability increased by 14% compared to the normal shoulder after the Latarjet procedure. Stability increased significantly with increases in the load applied to the subscapularis and conjoint tendons at the mid-range arm position. Relative surgical indications are (1) a Bankart lesion or its variants, such as Perthes lesion, anterior labroligamentous periosteal sleeve avulsion (ALPSA) lesion, (2) glenoid labral articular defect (GLAD) lesion, (3) shoulders without a glenoid defect, and (4) humeral avulsion of the glenohumeral ligament (HAGL) lesion. Although our studies simulated a shoulder with a glenoid defect, the results of an unpublished preliminary study confirmed that a shoulder without a glenoid defect became stable after performance of the Latarjet procedure. Contra-indications are (1) dysfunction of the subscapularis or conjoint tendon and (2) young patients with open growth plate. If the subscapularis or conjoint tendon is dysfunctional for some reason, one cannot expect the sling effect to be produced by these 2 tendons.

Difference Between Latarjet and Bristow Procedures

There are 2 coracoid transfer procedures (the Bristow and Latarjet procedures), which are frequently used to treat a large glenoid defect in patients with anterior shoulder instability. Giles et al[14] compared the biomechanical effects of these 2 procedures and they reported that both procedures have equivalent stabilizing effects in shoulders without glenoid defect. However, the Latarjet procedure conferred superior stabilization in shoulders with 30% glenoid defect compared to Bristow procedure. Nourissat et al[15] assessed the effect of the position of the bone graft on anterior and inferior stability. They showed that the lying position at 4 o'clock substantially decreased anterior and inferior displacement of the humeral head respectively. The standing bone-block position did not affect translation.

Is Coracoid Process Large Enough for the Latarjet Procedure?

As the Latarjet has gained in popularity, the question arises if the CP is large enough for the Latarjet procedure in smaller proportioned peoples? Takahashi et al[16] investigated the dimension of the CP of Japanese patients. The DICOM data of CT images of 102 shoulders from 51 Japanese patients with unilateral anterior instability were reviewed. The CP maximum length, the average width, and the average height were measured for the affected and unaffected side. The transferable CP length was defined as the difference between the CP length and the width of the coracoid base. The mean length of the transferable CP was 28.5 mm in the affected side and 29.1 mm in the unaffected side. The transferable CP length in the affected side was significantly shorter than that of the unaffected side. There were 5 women in 7 cases (14%) who had shorter CP lengths than the ideal length. It was reported that the Latarjet procedure transferred most of the coracoid as a bone graft that usually measured 2.5-3 cm in length.[17] Our results revealed that the less ideal cases for the Latarjet procedure were mostly observed in women and its total incidence was 14%. Surgeons should measure the size of CP preoperatively in the planning of Latarjet procedure for smaller patients.

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