The Stabilizing Mechanism of the Latarjet Procedure
A Cadaveric Study

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Background: The Latarjet procedure has been used commonly for extra-articular treatment of anterior glenohumeral joint instability. Recently, the technique also has been used as a bone-grafting procedure to repair large glenoid defects. The "sling effect" and the "bone-block effect" have been proposed as the stabilizing mechanisms of this procedure. The aim of this study was to determine the stabilizing mechanisms of this procedure.

Methods: Eight fresh-frozen shoulders were prepared and tested with use of a custom testing machine instrumented with a load cell. With a 50-N axial force applied to the humerus, the humeral head was translated anteriorly. Translational force was measured at both the end-range and the mid-range arm positions, with the capsule intact, after creation of a Bankart lesion, after creation of a large glenoid defect, and after the Latarjet procedure with no load and then three different sets of loads applied to the subscapularis and conjoint tendons. Then, these two tendons were removed to observe the contribution of the sling effect to the stability. Finally, the sutures attaching the coracoacromial ligament to the capsular flap were removed in order to observe the effect of that attachment.

Results: The translational force, which decreased significantly after creation of a Bankart lesion or a large glenoid defect, returned to the intact-condition level after the Latarjet procedure was performed. At the end-range arm position, the contribution of the sling effect by the subscapularis and conjoint tendons was 76% to 77% as the load changed, and the remaining 23% to 24% was contributed by the suturing of the capsular flap. At the mid-range position, the contribution of the sling effect was 51% to 62%, and the remaining 38% to 49% was contributed by the reconstruction of the glenoid.

Conclusions: The main stabilizing mechanism of the Latarjet procedure was the sling effect at both the end-range and the mid-range arm positions.

Clinical Relevance: The Latarjet procedure remains an effective procedure for restoring stability to an unstable glenohumeral joint, particularly when there is glenoid bone deficiency.

Surgical stabilizing procedures for treating anterior instability of the glenohumeral joint can be divided into two groups: intra-articular and extra-articular. Intra-articular stabilizing procedures include the Bankart repair, and extra-articular techniques include the Latarjet procedure. The coracoid transfer procedures lost popularity for a period of time after a high rate of postoperative osteoarthritis was reported1-3. However, recent reports1-6 have shown that postoperative arthritis can be avoided by appropriate positioning of a coracoid bone graft. Coracoid transfer procedures for the treatment of shoulders with a large glenoid defect have therefore gained popularity once again7-10.

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 reported4,11-15. Clinicians believe that the stabilizing mechanism of this procedure is the “sling effect” of the subscapularis4,16,17 or conjoint tendon7,11 or the “bone-block effect.”16 To date, few biomechanical studies have demonstrated the stabilizing mechanism of Latarjet procedures18. The aim of the present study was...
to determine the stabilizing mechanism of this extra-articular stabilizing procedure for shoulders with anterior instability and with a large glenoid defect. Our hypothesis was that the main stabilizing mechanism of this procedure was the sling effect at the end-range arm position and reconstruction of the glenoid concavity at the mid-range position.

Materials and Methods

Specimen Preparation

Eight fresh-frozen shoulders from seven men and one woman with a mean age at the time of death of seventy-five years (range, fifty-two to ninety-three years) were used. The shoulders were screened for rotator cuff tears and radiographic evidence of moderate to severe glenohumeral osteoarthritis. The subcutaneous soft tissues were removed except for the rotator cuff muscles. The body of the scapula was removed, and the glenoid was potted in a container that was attached to a custom mechanical testing device (Avalon Technologies, Rochester, Minnesota). In order to orient the glenoid articular surface accurately parallel to the floor, two Kirschner wires were passed through the glenohumeral joint before testing was performed.

Testing Apparatus (Fig. 1)

The testing device consisted of a six-component load cell (model 45E15A-E24ES-A; JR3, Woodland, California) mounted on a motorized x-y table. The x axis and y axis were defined as the anterior-posterior and superior-inferior directions, respectively, and the z axis (i.e., vertical) was defined as the medial-lateral direction. The vertical movement of the humeral head was measured with a linear potentiometer (TR-50; Novotechnik, Stuttgart, Germany) attached to the sliding device. According to the manufacturer, the linearity of this potentiometer was 0.15%. The horizontal movement of the humeral head was measured with a second linear potentiometer (LCPL Open Frame Linear Potentiometer; State Electronics, Oceanside, California) attached to the x-y table. The linearity of this second potentiometer was 0.5%. A 50-N axial force was applied to the humeral head with use of a pneumatic cylinder. This specific value of 50 N was determined on the basis of previous studies. Lazarus et al. reported that, with active in vivo abduction, the force normal to the glenoid was always >50 N. In addition, it was demonstrated that, with an applied compressive load of 50 N, dislocation did not cause gross damage to the tissue.

Testing Protocol

First, the neutral position was determined by measuring the humeral head position when it was seated most medially in the glenoid. This reference neutral position was used for the subsequent displacement-controlled study. Because the value of the translational force was affected by the humeral head position, it was important that the humeral head started from the neutral position. The humeral head was translated anteriorly for 10 mm at a rate of 2 mm/sec. All specimens were tested with use of this 10-mm-displacement protocol. However, the force analysis was based on a normalized displacement that was proportional to the glenoid length (superior-inferior dimension). The 10-mm displacement distance was used for the longest glenoid (37 mm); the displacement distances for all other glenoids were downscaled accordingly. The translational force occurring at a normalized displacement of 8.5 ± 0.72 mm (range, 7.6 to 10 mm) was used.

Arm Positions

Because the main stabilizing mechanisms could differ between the end-range and mid-range positions of the glenohumeral joint, we used both for testing. We used 60° of abduction relative to the scapula (90° of abduction relative to the trunk) in the scapular plane and maximum external rotation to simulate the end-range position, and we used 60° of abduction in the scapular plane and neutral rotation to simulate the mid-range position. These positions were determined on the basis of previous studies. The screw inserted perpendicular to the humeral shaft was used as a reference point for neutral rotation of the humerus. The maximum external rotation was established by applying a constant torque to the humeral head.
Test Conditions

The translational force was measured under eight conditions at the end-range and mid-range arm positions. The eight conditions were (1) with the capsule intact, (2) with a simulated Bankart lesion, (3) with a large glenoid defect (Fig. 2), (4) after the Latarjet procedure without load, (5) after the Latarjet procedure with load (described later) applied to the subscapularis and conjoint tendons, (6) after removal of these two tendons, (7) after removal of the sutures connecting the coracoacromial ligament to the capsular flap, and (8) after release of the attachments of the anterior aspect of the capsule to the glenoid labrum. A Bankart lesion was simulated by elevating the capsulolabral insertion from the glenoid from the two o’clock to the eight o’clock position in the right shoulder. In addition, the continuity of the labrum was transected at three o’clock with use of a knife.19,24 A large glenoid defect was created in order to determine the contribution of the coracoid process graft to the stability of the joint. This 6-mm defect of the glenoid width was biomechanically demonstrated to be the critical size of the glenoid defect.24 Osteotomy was performed parallel to the longitudinal axis of the glenoid, centered at the three o’clock position. The subscapularis and conjoint tendons were released from loading (but not cut) so that the contribution of the sling effect to stability could be observed. The sutures attaching the coracoacromial ligament were removed in order to see the effect of this attachment on stability. The anterior aspect of the capsule (from the twelve o’clock to the six o’clock position) was then released so that the effect of reconstruction of the glenoid could be discerned.

Three sets of loads were applied with use of pulleys and weights to determine the relationship between the loading of muscles and the translational force; 10 N and 2.5 N, 20 N and 5 N, and 30 N and 7.5 N were applied to the subscapularis and conjoint tendons, respectively. The actual force of the subscapularis muscle with the arm positioned in abduction and neutral rotation has been calculated to be 58 N.29 However, only one-third (20 N) of this force was chosen as the base load applied to the subscapularis tendon because of concern that the muscles might be damaged if the full 58-N load were applied. We determined the ratio of those loads on the basis of the relative

![Fig. 2](Photograph of a large glenoid defect, which was a 6-mm defect of the glenoid width (26% of the glenoid surface) created at the three o’clock position.)

![Fig. 3](Graph showing the stability at the end-range position. The translational force, which significantly decreased after creation of a Bankart lesion, significantly increased after the Latarjet procedure was performed. The force significantly decreased after removal of the subscapularis (SSC) and conjoint tendons. The force further decreased after removal of the sutures to the capsular flap. The translational forces are expressed as the mean and the standard deviation. *P < 0.05 compared with the intact condition. **P < 0.05 compared with the Bankart lesion. †P < 0.05 compared with the Latarjet procedure. ‡†P < 0.05 compared with the condition after removal of the subscapularis and conjoint tendons. Remove SSC&conj = after removal of the two tendon loads. Remove CAL = after removal of the sutures of the coracoacromial ligament. Cut ant capsule = after release of the attachments of the anterior aspect of the capsule to the glenoid labrum.)
physiological cross-sectional areas of each muscle. The ratio between the subscapularis muscle and the short head of the biceps and coracobrachialis muscles was 4:1.

### Surgical Procedure

The surgical procedure was performed as described by Walch and Boileau\(^4\). The subscapularis muscle/tendon was divided at the superior two-thirds junction. The distal 2 cm of the coracoid process was osteotomized with use of a small angulated saw, and a portion of the coracoacromial ligament was retained. The bone block was positioned flush to the anterior-inferior glenoid margin. It was transferred to the glenoid neck after a small capsulotomy (1.5 cm), removal of the labrum, and decortication of the glenoid. If necessary, the graft was contoured with a power burr to fit the shape of the glenoid. Two AO 4.5-mm malleolar screws were driven into the posterior cortex. The coracoacromial ligament remnant on the coracoid process was sutured to the anterior capsular flap. Finally, the horizontal split in the subscapularis was sutured. A Bankart repair was not performed.

### Data Analysis

One-way repeated-measures analysis of variance was used to compare the forces and humeral displacements among the different capsule and glenoid conditions. When a significant effect was observed, the Dunnett multiple-comparisons procedure was used to determine which individual values differed from one another. This procedure was also used to compare the forces among three different load conditions. Statistical analysis was performed with use of StatView software (SAS Institute, Cary, North Carolina), with significance set at \(p < 0.05\). With eight cadaveric shoulders in each group, there was an 80% power to detect an effect size of >1.2, with the effect size defined as the mean of the change divided by the standard deviation of the change.

### Source of Funding

The equipment and devices used for this study were purchased with funding provided by the Mayo Foundation and the Uehara Memorial Foundation.

### Results

#### End-Range Position (Figs. 3 and 4)

The translational force decreased significantly after creation of the Bankart lesion \((p < 0.001)\) and after creation of the large glenoid defect \((p < 0.001)\). The force increased significantly after the Latarjet procedure without loading \((p < 0.0026)\). There was a significant difference between the forces measured after the Latarjet procedure with no loading and all of those measured after the Latarjet procedures with loading \((p < 0.0001)\), although the force remained unchanged after...
Mid-Range Position (Figs. 5 and 6)
The translational force decreased significantly after creation of either a Bankart lesion (p < 0.001) or a large glenoid defect (p < 0.001). After the Latarjet procedure without loading, the force increased significantly (p < 0.001). The force increased significantly (p = 0.004) with increases in the load. After removal of the two tendon loads, the force decreased significantly (p = 0.005). However, the force did not significantly decrease again after removal of the sutures to the capsular flap or after release of the anterior aspect of the capsule. The difference between the magnitude of force under the “glenoid defect-created” condition and that under the “Latarjet procedure-performed” condition corresponded to the change in stability. Again, with this latter stability defined as 100%, the force reduction after removal of the two tendons was 51% ± 3% (p = 0.010), 57% ± 3% (p = 0.001), and 62% ± 2% (p < 0.001), respectively, under the three sets of loads. The force did not decrease further after removal of the sutures to the capsular flap or after release of the anterior aspect of the capsule. Thus, because the mean contribution of the sling effect to stability was 51% to 62%, the glenoid reconstruction, by process of elimination, contributed the remaining 38% to 49%.

The lateral humeral displacement decreased significantly both in the shoulders with a Bankart lesion and in those with a large glenoid defect (p < 0.001 and p < 0.001, respectively). The displacement increased significantly after performance of the Latarjet procedure. The displacement values are expressed as the mean and the standard deviation. *p < 0.001 compared with the intact condition. **p < 0.001 compared with a large glenoid defect. Remove SSC&conj = after removal of the two tendon (subscapularis and conjoint) loads. Remove CAL = after removal of the sutures of the coracoacromial ligament. Cut ant capsule = after release of the attachments of the anterior aspect of the capsule to the glenoid labrum.

Discussion
There have been few reports biomechanically clarifying the stabilizing mechanism of the Latarjet procedure. The present data show that the translational force was restored to the intact-condition level after the Latarjet procedure was performed. The shoulder became stable after the procedure even if there was a Bankart lesion with a large glenoid defect. It was demonstrated that the main stabilizing mechanism of the Latarjet procedure was the sling effect produced by the subscapularis and conjoint tendons. If the subscapularis or conjoint tendon is dysfunctional for some reason, one cannot expect the sling effect to be produced by these two tendons. Although a Bankart repair was not performed, our results showed that suturing of the coracoacromial ligament created a capsular-repair effect, indicating that an effect equivalent to that of a Bankart repair can be expected from suturing of the coracoacromial ligament. Another clinical implication of this study is that the Latarjet procedure provides more stability than is present in the normal shoulder at the end-range of motion, providing a rationale for performing the Latarjet procedure in patients at high risk for recurrence, such as athletes who participate in collision sports.

At the end-range arm position, 76% to 77% of the stability was contributed by the sling effect. The remaining 23% to 24% was contributed by suturing of the coracoacromial ligament. In the mid-range position, the contribution of the...
The main stabilizing mechanism of the Latarjet procedure was the sling effect produced by 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. The transferred coracoid process was fixed with two screws. The split subscapularis tendon provided muscle stability, working as a barrier because the intersection of the transferred conjoint tendon added tension to the inferior portion of the subscapularis.

After creation of a large glenoid defect, the force decreased at the mid-range position because of a loss of concavity of the glenoid. The data also showed that the force returned to the normal level after the transfer of the coracoid process. The effect of the transplant was not due to the bone-block effect (i.e., extension of the glenoid rim and blockage of the humeral head) but rather to a glenoidplasty effect (i.e., reconstruction of the glenoid concavity, positioning the coracoid process flush to the glenoid margin) as reported by Walch and Boileau. Because the position of the coracoid transplant differs between the Latarjet and Bristow procedures, the position of the transferred conjoint tendon also differs. However, we think that the main stabilizing mechanism of the Bristow procedure is the sling effect, similar to what we reported for the Latarjet procedure, although there may be a slight difference in terms of the anatomical structures contributing to the stability of the joint. One should always think about a possible humeral head defect when considering a glenoid defect because glenoid defects are associated with a high incidence of Hill-Sachs lesions. According to our previous biomechanical study, if there is an osseous defect of the glenoid, then the risk of the engagement between the humeral head and the glenoid increases. Therefore, when one considers the critical size of a Hill-Sachs lesion, one should also think about the size of the glenoid deficiency.

The current study had several limitations. First, the sling effect was demonstrated experimentally under a relatively small amount of load, which may be different from the in vivo condition. However, it was inadvisable to apply the...
same load to the cadaveric shoulders as is applied to shoulders in the living body because of a high likelihood of causing muscle damage to the cadaveric shoulders. Because the in vivo muscle force of the subscapularis is large (on the order of 58 N), the sling effect may well contribute >62% during activities of daily living. Second, the weights that were measured to the subscapularis and conjoint tendons may differ from the corresponding loads present in vivo. Therefore, the measured sling effect may differ from that in living patients. Third, the specimens were tested with a 10-mm-displacement protocol. The humeral head normally would translate >10 mm during shoulder dislocation. Our experimental condition is therefore different from the actual condition in patients with anterior instability. However, if the humeral head were to be experimentally translated until dislocation, the soft tissues surrounding the shoulder joint would be at high risk of damage, precluding completion of the subsequent testing sequences.

In conclusion, under these experimental conditions, the main stabilizing mechanism of the Latarjet procedure was the sling effect produced by the subscapularis and conjoint tendons, at both the end-range and mid-range arm positions. The remaining stability arose from suture of the coracoclavicular ligament to the capsular flap at the end-range position, and from glenoid cavity reconstruction at the mid-range position. It was demonstrated that the Latarjet procedure provided a superior stabilizing mechanism for shoulders with anterior shoulder instability in the presence of a glenoid defect.

References


