Biomechanical Study of Direct and Patch Repairs of the Torn Rotator Cuff

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The outcome of surgical repair of complete rotator cuff tears varies substantially and one technique has not been uniformly successful. We hypothesize that the integrity of the rotator cuff, including its ability to transmit force, can be restored through either direct or patch repair. However, the stability and kinematics of the glenohumeral joint are different following each type of repair. The goal of this study is to compare the resulting constraint and kinematic changes on the glenohumeral joint following direct and synthetic patch repairs of a torn rotator cuff. Twelve fresh-frozen cadaveric shoulders were used. Direct repair with sutures passing perpendicular to the muscle line of action, and synthetic patch repair with sutures at the edge of the circular graft were performed for comparison. Stability tests were performed in three clinically relevant positions. In general, the joint laxity, as represented by the displacement ratio, increased significantly in the inferior direction and moderately in the anterior and posterior directions when the defects were created at either the critical area or rotator interval. After either patch repair or direct repair, the joint laxity was reduced but not restored to the level of intact condition. Stability of the glenohumeral joint after repair is another important factor to consider during surgical planning. This study substantiates that the use of synthetic fabrics to bridge rotator cuff defects compared with using direct repair achieves equivalent results in reducing the joint laxity and restoring joint stability. **(Mid Taiwan J Med 1999 ; 4 : 29-37)**

Key words

biomechanics, repair, rotator cuff tear

INTRODUCTION

Rotator cuff tear was first identified in 1835 by Smith, an English anatomist [1]. However, little was reported concerning the operative treatment until 1911, when Codman described the first operative repair of a rotator cuff tear [2]. The results of rotator cuff repairs improved significantly after Neer's report on anterior acromioplasty in combination with cuff mobilization and repair in 1972 [3].

It is well recognized that the defect still can not be sutured end-to-end without tension in patients with moderate rotator cuff tears. Therefore, McLaughlin attempted to freshen the torn cuff and attach it to the humeral head at whatever point it could reach without tension [4]. However, for repairs of the remaining chronic massive rotator cuff tears, the McLaughlin technique cannot be applied. Many authors have developed their own methods [5-7]. Those methods described hitherto have not been consistently successful and have been associated with higher incidence of failure because the supraspinatus muscles or biceps tendons may be too small to

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Fig.1 Direct repair was performed with sutures passing perpendicular to the muscle line of action.

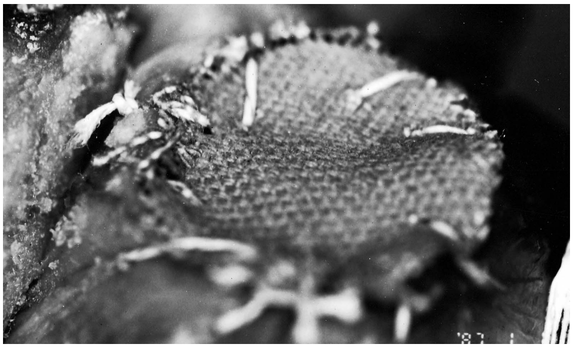

Fig.2 Patch repair was made with sutures at the edge of the circular synthetic patch graft.

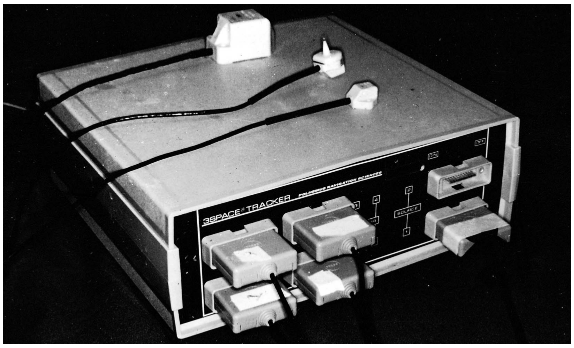

Fig.3 Magnetic tracking system.

bridge massive defects. Furthermore, the autogenous substitute materials, such as fascia lata or other tendons, tend to wear and stretch. Conversely, synthetic fabrics possess high tensile strength and low friction and bring about excellent tissue reactions when used as a surgical prosthesis [8].

According to the concept of the "tendinous glenoid", Ozaki et al. reconstructed chronic massive rotator cuff tears with synthetic materials [8]. On the basis of biomechanical and clinical considerations the authors found that the use of synthetic fabrics to bridge the cuff defect leads to satisfactory functional results. On the other hand, Post used carbon filament to repair the torn cuff and found it to be no better than repair with conventional techniques [9].

The outcome of surgical repair of complete rotator cuff tears varies substantially and one technique has not been uniformly successful. We hypothesize that the integrity of the rotator cuff, including its ability to transmit force, can be restored through either direct or patch repair. However, the stability and kinematics of the glenohumeral joint are different following each type of repair. The goal of this study is to compare the resulting constraint and kinematic changes on the glenohumeral joint following direct and synthetic patch repairs of a torn rotator cuff.

MATERIALS AND METHODS

Twelve fresh frozen cadaveric shoulders (six right and six left) were used. They were from twelve subjects (six males and six females) ranging in age from 54 to 76 years (mean 64.4 years) and had no radiographic evidence of glenohumeral osteoarthritis. Prior to the test, a distal midhumerus transection was performed below the deltoid insertion with a K-wire inserted parallel to the bi-epicondyle line of the distal humerus in order to keep the orientation of the humerus. In this manner, the rotation of the proximal humerus could be accurately determined at the time of experimentation. The specimens were thawed for preparation 24 hours before the experiment. All soft tissues and muscles were removed except the deltoid, rotator cuff and the long head of the biceps, which were loaded through a pulley-cable system at the direction of the line of muscle action. The loading measurements were estimated [10] using the muscle cross-sectional area and electromyography data in certain positions as previously reported in the literature [11-15]. Careful dissection was made to allow isolation of the anterior, middle and posterior portions of the deltoid muscle and to facilitate cable attachment. Sutures were placed in the middle of the tendinous portion of each muscle to permit muscle loading. Displacement measurements were made from an applied translation force. Forty-five newtons of translation load were applied to each. Two fiberglass pins were inserted perpendicular to each other (one anteroposterior and the other medial-lateral) as close as possible to the humeral head (HH) for the application of the translation forces. Using a special cutting blade for consistency, a circular (2.5 cm in diameter) defect was created at either the critical area (Group I, six specimens) or, the rotator interval (Group II, six specimens). Direct repair with sutures passing perpendicular to the muscle line of action (Fig. 1), and synthetic patch (Cotton Duck Fabric, Rochford Supply Inc, Minneapolis, Minn) repair with sutures at the edge of the circular graft (Fig. 2) were performed for comparison. The stability tests were performed in three clinically relevant positions: inferior, using sulcus test in hanging position; anterior, using 90^0 abduction with 90^0 external rotation; and posterior, using 90^0 flexion with maximal internal rotation [16-18].

The scapula was mounted on a Plexiglas shoulder loading frame [10], which allowed for adjustments in the inclination of scapula and application of a magnetic tracking device (Fig. 3), 3Space Tracker System (Polhemus Navigation Sciences Division, Colchester, VT) for the measurement of kinematics of the humerus in relation to the glenoid. Additional use of cement ensured the scapular rigidity during loading. A fiberglass rod was inserted into the medullary canal and cemented or press-fit in the proximal humerus and a rotational control device was used for guidance of this intramedullary rod to control the motion of the shoulder. Another pin was inserted in the distal humerus to control the rotation of the humerus. The displacement ratio (DR) was calculated and normalized by dividing the length of the glenoid for inferior instability and the width for anteroposterior instability.

According to the specifications, the 3Space Tracker System, has a translation resolution in the 0.001 cm/cm range, and an angular resolution of 0.1^0. The source was fixed on the movable portion of the frame, and therefore, fixed on the scapula. One sensor was mounted on the proximal humerus. After the test, another sensor was used to digitize the bony marks on the glenoid relative to the source, and on the humerus relative to the humeral sensor for determination of the their coordinate systems. The humeral articular surface relative to the humeral sensor and glenoid surface relative to the source were measured for calculations of joint contact characteristics. The origin of the coordinate system was established at the center of the glenoid. This center was determined by the intersection of the vertical and horizontal axes of the glenoid. The z-axis was defined as a line that went through the origin and was parallel to a line along the medial border of the scapula (i.e., the superoinferior axis). This latter line was defined by the digitization of two points: 1) the inferior angle of the scapula and 2) the intersection of the medial border of the scapula and the scapular spine. The x-axis was defined as a line that went through the origin and was perpendicular to the line along the medial border of the scapula (i.e., the mediolateral axis). The y-axis was defined as a line that went through the origin and was perpendicular to both the x- and z-axes (i.e., the anteroposterior axis) [10].

The center of the HH in relation to the sensor was calculated in two ways that gave very similar results. First, the articular surface of the HH was digitized. The data were fitted to a spherical surface using a least square regression method, and the center of this sphere (i.e., the geometric center of the HH) was then determined. Second, the humerus was pivoted on its articular surface against the rim of a smooth cylinder-shaped object, with the head able to glide freely. Real-time data

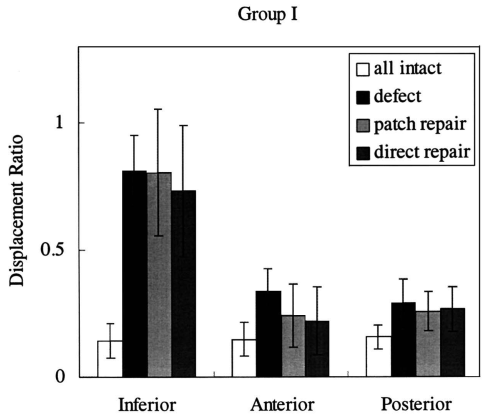

Fig.4 In Group I, the joint laxity increased significantly in the inferior direction and moderately in the anterior and posterior directions. After either patch or direct repair, the joint laxity was reduced but not restored to the level of the intact conditions. There was no statistical difference in the reduced joint laxity between direct and patch repair methods.

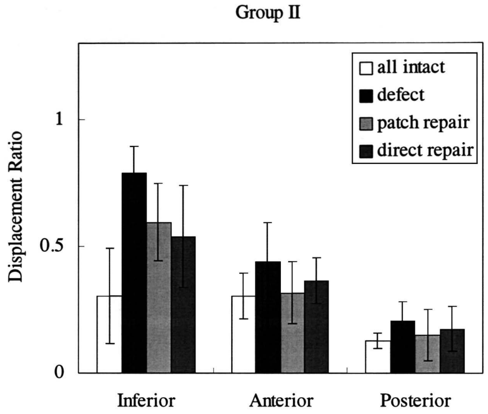

Fig.5 In Group II, the joint laxity increased significantly in the inferior direction and moderately in the anterior and posterior directions. After either patch or direct repair, the joint laxity was reduced but not restored to the level of the intact conditions. There was no statistical difference in the reduced joint laxity between direct and patch repair methods.

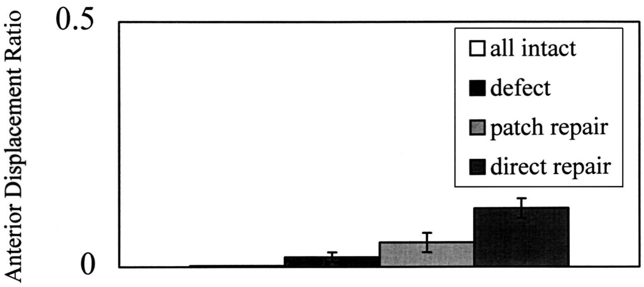

Fig.6 When the arm in 90° flexion, all three conditions allowed the humeral head to shift to the anterior, and the effects of direct repair were greater than patch repair, the anterior displacement ratio of direct repair increased up to 0.12.

from the sensor on the shaft were recorded. The pivot point (i.e., the point that was most nearly equidistant from the data points collected) was calculated using a least square regression method, and was believed to represent the kinematic center of the humeral head. The displacement of the center relative to the glenoid coordinate system was recorded.

All the defects were created with a special-designed cutting blade in a hanging position for consistency because injury of the static constraints, such as capsule, glenohumeral ligament (GHL) and coracohumeral ligament (CHL), would be different if defect-creation occurred in different arm positions. Repeated measurements for ANOVA were used to detect the difference between the intact and defect groups. Then a two-sample *t*-test was used to detect any differences between the two groups with the same repair technique. A p value of < 0.05 was considered statistically significant.

RESULTS

Stability

In general, the joint laxity, as represented by the DR, increased significantly in the inferior direction ($p<0.01$) and moderately in the anterior direction and posterior directions ($p<0.05$) when the defects were created at either critical area (Fig. 4) or rotator interval (Fig. 5). After either patch repair or direct repair, the joint laxity was reduced but not restored to the level of the intact condition

(Fig. 4 and 5). For the defects created at either critical or rotator interval areas, there was no statistical difference in the reduced joint laxity between direct and patch repair methods (Fig. 4 and 5).

Group I. For inferior stability, the inferior DR of the sulcus test of direct repair was less than that of the patch repair, but there was no statistical difference (Fig. 4). For the anterior stability, the difference of anterior DR between the direct repair group and defect group was greater than the difference between patch repair and defect group (Fig. 4). Conversely, the posterior DR of the direct repair group was greater than that of the patch repair group, but the difference was quite small (Fig. 4).

Group II. For inferior stability, the difference between direct repair group and defect group was greater than the difference between patch repair group and defect group (Fig. 5). For anterior stability, the difference of anterior DR between defect and patch repair groups was obvious (Fig. 5). For posterior stability, the difference of posterior DR between direct repair and defect groups was less than the difference between patch repair and defect groups (Fig. 5).

Kinematics

Group I. Without translation load and the arm in hanging position, the defects allowed the HH superior to migrate and patch repairs did not change the shifting direction of HH (i.e. to superior). Conversely, direct repairs allowed the HH shifted to inferior. In 90^0 of abduction, the defects allowed the HH posterior and inferior to migrate and both patch and direct repairs did not change the shifting direction of HH (inferior and posterior). When the arm was in 90^0 flexion, defect allowed the HH anterior to shift and the HH shifted to the anterior in the patch and direct repair groups and the effects of the direct repair were greater than of the patch repair, the anterior DR of direct repair group increased up to 0.12 (Fig. 6).

Group II. Without translation load and the arm in hanging position, the defects allowed the HH shift to the anterior and patch repair did not change the HH shifting direction (i.e. anterior). Conversely, the direct repair allowed the HH shift to the posterior. In 90 degrees of abduction with 90 degrees of external rotation, the defects allowed the HH shift to the posterior and the direct repair allowed the HH to shift more in the posterior direction. In 90^0 of flexion, the defects allowed the HH shift to the posterior and the patch-repair also allowed the HH to shift to the posterior. Whereas the HH migrated to the anterior in the direct repair group.

DISCUSSION

The outcome of surgical repair of complete rotator cuff tears varies substantially and one technique has not been uniformly successful. A surgical alternative to direct repair is the insertion of the cuff edges into a trough made in the HH and a variety of procedures have been advocated to aid in mobilization and restoration of tendon defect. These techniques include mobilization of existing tendon [7,19,20], transposition of tendons [21,22], transfer of tendons and muscles [23], implantation of fascia [24,25], allograft [5], and synthetic material [8]. However, the use of fascia lata has not always been successful because the material tends to be stretch, and biceps grafts may be too small to cover massive defects [26].

When repairing the cuff defect, orthopedic surgeons usually face the dilemma of restoring the integrity with good stability or normal kinematics. When the torn cuff edge retracts proximally which cannot be easily pulled out, or a large defect over the HH remains, the use of synthetic fabrics is indicated [8]. Synthetic fabrics can be used as ideal substitutes for the rotator cuff because they provide quick coverage with satisfactory connective tissue proliferation; they keep firm attachment with the recipient bed; they make less adhesion with the neighboring tissue; and they endure mechanical stress well and maintain their original tensile strength after implantation [8]. However, muscle activity occurs simultaneously both in agonistic and antagonistic muscles and should also be considered because coordination due to muscle contractions plays a significant role in stabilizing the shoulder joint [27]. According to the concept of the “tendinous glenoid”, Ozaki et al. reconstructed chronic massive rotator cuff tears with synthetic materials and recommended that the implanted synthetic materials be as thick as the normal rotator cuff for greater muscle strength [8].

Based on our results, direct repair had merit in its simplicity and relative stability. However, the kinematics of the glenohumeral joint were changed in both critical area and rotator interval tears. On the other hand, patch repair had merit in relative stability and some kinematics. However, muscle coordination, cuff-patch junction and material strength problems should be also be addressed in real conditions. For the defects created at either critical or rotator interval areas, there was no statistical difference in reducing joint laxity between direct and patch repair methods. It may be due to the moderate size of the defects we created. It has generally been believed that force transmission of a torn rotator cuff could be maintained through either direct or patch repair. Stability of the glenohumeral joint after repair is another important factor to be considered during surgical planning. This study substantiates that the use of synthetic fabrics to bridge rotator cuff defects, compared with using direct repair, achieves equivalent results in reducing the joint laxity and restoring joint stability.

Harryman et al. reported the correlation of functional results with integrity of the cuff [28]. They found 80% of the repairs of a tear involving only the supraspinatus tendon were intact at follow-up, while more than 50 % of the repairs of a tear involving more than the supraspinatus tendon had recurrent defects. If direct repair is used, adequate mobilization of retracted, scarred rotator cuff tendons is important to achieve a successful repair. In terms of cuff edges, Rathburn and Macnab [29] suggested that the edges of the rotator cuff were avascular and should be debrided. However, recent work by several authors [30,31] suggests that the edges of the cuff are in fact well vascularized and should be preserved. Swintowsky et al. used intraoperative laser Doppler flowmetry to assess cuff vascularity in living patients with clinical symptoms of impingement and cuff tears [30]. Uhtoff et al. analyzed intraoperative specimens from the margins of 100 complete rotator cuff tears [32]. They also believed there was a significant amount of granulation tissue at the edges of the tissue and that these edges were well vascularized. The principal point in the repair is the restoration of normal tension in the rotator cuff muscles. Thus, it may be necessary to abduct the arm to appose the cuff edges to its bony insertion. Secondary rupture after repair is associated with very poor results and re-operation usually fails to improve function although it may relieve pain [9,28,33]. A successful first operation has the best chance of relieving both pain and disability. Biomechanical studies of the shoulder suggest that forces passing through the rotator cuff are greatest during abduction and may be approximately half the body weight [34]. Most repairs are undertaken in elderly patients and, in terms of these high forces, the quality of the bone of the greater tuberosity is very important.

The cuff muscles serve several stability functions: 1) by its passive bulk, 2) by developing muscle tensions that compress the joint surfaces together, 3) by moving the humerus with respect to the glenoid and thereby tightening static restrains, and 4) by limiting the arc of motion of the glenohumeral joint by muscle tensions [35]. With the present technology, it is impossible to develop a model, either *in vitro* or *in vivo*, that allows simultaneous modeling of all four of these stabilizing models of the rotator cuff. However, we can create a rotator cuff model, which is similar to the real physiologic and pathologic conditions because the "created defect" can decrease the muscle bulk, muscle tension and loss of the constraint of the capsuloligamentous complex, but preserve the bridging effect of the surrounding muscles. In addition, dynamic stability is the most effective when the contractions of all shoulder muscles are coordinated with each other. The reason the joint laxity increased significantly in inferior direction and moderately in anterior and posterior directions is due to concomitant sectioning of superior and middle GHL and CHL in Groups I and II and loss of the vacuum effect when venting the capsule. It also implies that biological healing is an important factor for restoration of the joint stability. The "created-defect" model is similar to the real physiologic and pathologic conditions because the model can quantitatively decrease the muscle bulk, muscle tension and loss of the constraint of the capsuloligamentous complex, but preserve the bridging function of the surrounding muscles. It is also evident that the synthetic patch graft can transmit force in our study.

Without the translation load, the effect of defect on HH kinematics might disturb the proprioception and cause functional instability sensation during daily activities. In Group I, the defects allowed the HH superior to migrate to the hanging position, which might be due to the loss of the barrier effect of the supraspinatus. With the arm in 90^0 of abduction and 90^0 of external rotation in Group I, the defect allowed the HH to migrate to the posterior, which might be due to the shifting of defect from superior to posterior as the angle of external rotation increased. Whereas in Group II, the defect allowed the HH to shift to the anterior and when the external rotation angle increased the HH reversed and shifted to the posterior. The loss of the barrier effect in the anterior direction in Group II allowed the HH to shift to the anterior, and when the defect shifted to the superior, it might lead HH to a reverse shift to the posterior. When the arm was in 90^0 flexion in Group I, the defect allowed the HH shifted to the anterior which might be explained by the pull of the subscapularis and the other strong internal rotators in the front. Whereas in Group II, the defect allowed the HH to inherently shift to the posterior, which might be due to loss of significant amount of subscapularis tension.

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肩部旋轉肌腱破裂以直接或補綻修補之生物力學研究

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肩部旋轉肌腱破裂以外科修補的方法很多，但事實上並非能達到一定的成功率。我們假設旋轉肌腱破裂以直接或補綻修補皆可恢復其完整性並能傳遞力量。但兩者對關節之穩定度及運動學上之結果應該不一樣。本研究之目的在探討這兩種手術方法之差異。實驗結果證實不論在一般旋轉肌腱最常破裂的地方或在旋轉肌交界處，當有破洞時會引起極度下方不穩定及中度之前方及後方不穩定。而當施行直接或補綻修補後可恢復一部分之穩定度，但還是無法達到正常之標準。所以，兩種手術方法在穩定度之影響相差無幾，而在肩關節運動學上之改變補綻修補比直接修補產生之不良改變較少。（**中台灣醫學科學雜誌 1999；4：29-37**）

關鍵詞

生物力學，修補術，旋轉肌破裂

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