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SHOULDER

Bankart repair versus Bankart repair plus remplissage: an in vitro biomechanical comparative study

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Abstract
Purpose To biomechanically compare Bankart lesion repair alone and Bankart lesion repair associated with infraspinatus capsulotenodesis described as «remplissage», in the treatment of combined Bankart and Hill-Sachs lesions.
Methods Seven pairs (right and left) of cadaveric shoulders have been tested, first without any lesion and then after performing a combined Bankart and Hill-Sachs lesions. For each pair, the specimens were then randomly assigned for Bankart lesion repair alone on one side or for Bankart lesion repair associated with remplissage on the other side. During tests, the shoulder was placed at 90° of abduction and at maximal external rotation, which value was recorded. A 50 N postero-anterior load was then applied to the proximal humerus, and the stiffness was calculated from the obtained load–displacement curve.
Results Bankart and Hill-Sachs lesions significantly ($p < 0.05$) decreased joint stiffness compared with intact joint. Bankart lesion repair alone did not restore stiffness to the level of intact, while adding the remplissage to the Bankart lesion repair did. External rotation was significantly increased after creation of the Bankart and Hill-Sachs lesion; Bankart repair restored the external rotation to the level of intact, while Bankart lesion repair associated with remplissage significantly decreased external rotation compared with intact and to Bankart lesion repair alone.
Conclusion In cadaveric shoulders with combined Bankart and Hill-Sachs lesions, Bankart lesion repair associated with remplissage restored intact joint stiffness contrary to Bankart lesion repair alone. This increase in stiffness was associated with a decrease in external rotation.

Keywords Shoulder instability · Hill-Sachs lesion · Bankart lesion · Remplissage · In vitro biomechanical study

Introduction

Recent studies [6, 14, 29, 36] with long-term results of arthroscopic Bankart lesion repair show less good results in terms of recurrence of instability than previous short- or medium-term studies. Osseous defects at the level of the humeral head (Hill-Sachs lesion) or at the level of the glenoid may compromise the shoulder's postoperative stability with recurrent dislocation as high as 89 % for contact athlete's with both bony lesions [4, 15, 32, 35, 38].

Many solutions for recurrent instability with engaging Hill-Sachs lesions have been proposed in the literature. One surgical option is the Latarjet-Bristow procedure [1, 5]. Other solutions have been proposed including osteochondral allograft transplantation [21], the Connolly procedure, an open procedure in which the infraspinatus tendon along with a piece of greater tuberosity is used to fill the humeral head defect [9], distal tibia allograft [30], or iliac crest bone graft to the anterior glenoid rim [38], and partial prosthetic resurfacing associated with Latarjet procedure [18, 26]. Most of these techniques require open surgery. Latarjet's

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procedure has recently been described as a full arthroscopic technique [22]. However, this arthroscopic Latarjet's option is technically rather demanding and does not strictly address the Hill-Sachs lesion, but rather the glenoïd bone lesion and some unstable shoulders may have large Hill-Sachs defect without significant glenoïd bone lesion requiring bone augmentation at the level of the glenoïd [2].

One interesting solution for those cases is the association of Bankart repair with posterior capsulotenodesis "remplissage" (French word for filling) procedure, arthroscopic-adapted procedure from the Connolly open technique, recently described by Wolf which is supposed to prevent engaging by transforming the Hill-Sachs lesion into an extra-articular defect [31]. Some of the recent clinical studies using this technique with mid-term follow-up seem to have promising results in terms of recurrence rate [3, 27, 28, 31].

In order to assess the biomechanical effects of the remplissage procedure, a biomechanical study was performed to compare the effect of Bankart capsulolabral lesion reconstruction alone to combined Bankart lesion repair and remplissage procedure on cadaveric shoulders with combined anterior Bankart lesion and posterior Hill-Sachs defect.

It is hypothesized that adding the remplissage procedure would increase shoulder stability compared with Bankart lesion repair alone, but with the possibility of external rotation restriction.

Materials and methods

Fourteen fresh-frozen cadaveric shoulders from seven cadavers were wrapped and stored at −20 °C until dissection. Median age at death was 79 years (53–99).

Before testing, each shoulder was thawed for 24 h, then dissected free of their extrinsic muscles. The four rotator cuff muscles were left intact. The study excluded the specimens that had a rotator cuff tear and signs of glenohumeral osteoarthritis.

The distal humerus was embedded in a custom-made box with a low melting point alloy (MCP 70, Mining and Chemical Products Ltd, Wellingborough, England). During the fixation procedure, we defined and materialized the referential axis system relative to the humerus using of three V-shaped pieces: two at the humeral epicondyles and one at the proximal part of the diaphysis (at 80 % of the humerus total length).

The scapular referential axis system was defined using three bony landmarks (the posterior angle of the acromion, the trigonum spina, and the inferior angle of the scapula). The scapula was fixed on a custom-made support with 3 anteroposterior clamps placed over these bony landmarks and 3 lateral clamps to stabilize it in all directions.

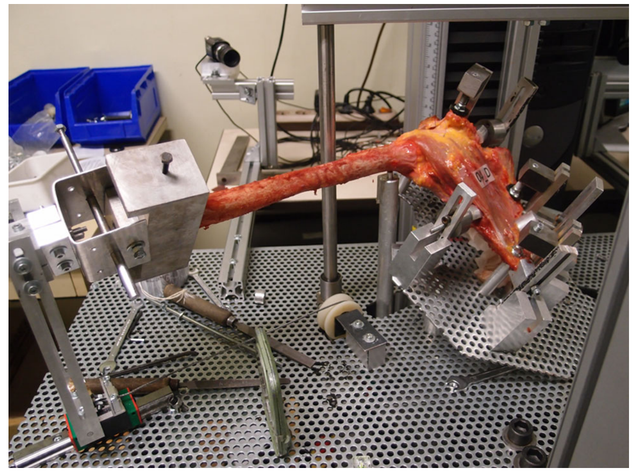

Fig. 1 Global configuration of the testing setup

The whole system was then fixed on a testing machine (Instron, Norwood, MA, USA) (Fig. 1). The scapulohumeral complex was set in a position that mimics the physiological position of 90° abduction in the frontal plane and maximal external rotation. The scapular position was at 22° of tilting and 17° of upward rotation, and the scapulo-humeral angle was set at 40° according to McClure et al. [23]. A preload of 22 N was applied along the diaphyseal axis to centre the humeral head on the glenoid [34, 37]. A 0.8 Nm external torque around the same diaphyseal axis was used to reach the maximal external rotation [16]. The humerus axial rotation was then locked at this maximal external rotation, and its value was measured using an inclinometer placed on the fixation box at the distal part of the humerus, with an accuracy of 0.5°. The humerus was free to move in the antero-posterior and medio-lateral directions during loadings.

On a first basis, the intact specimens were tested. A postero-anterior load of 50 N at 10 mm/min speed was applied on the proximal part of the humerus close to the lower insertion of the rotator cuff using the testing machine. The applied force was measured with a load cell with an accuracy better or equal to 0.25 % of the measured value. The resulting postero-anterior linear displacement of the humerus was measured at the loading point using a video camera tracking a landmark placed on the humerus (Fig. 2).The accuracy of the optical measurements was of 0.1 mm [11]. Load–displacement curves were obtained from which the stiffness of the specimen was calculated by linear regression on the most linear part of curve.

Then, we created a Bankart lesion from the 3 o'clock position to the 6 o'clock position opening only the rotator interval. Through the posterior interval between the

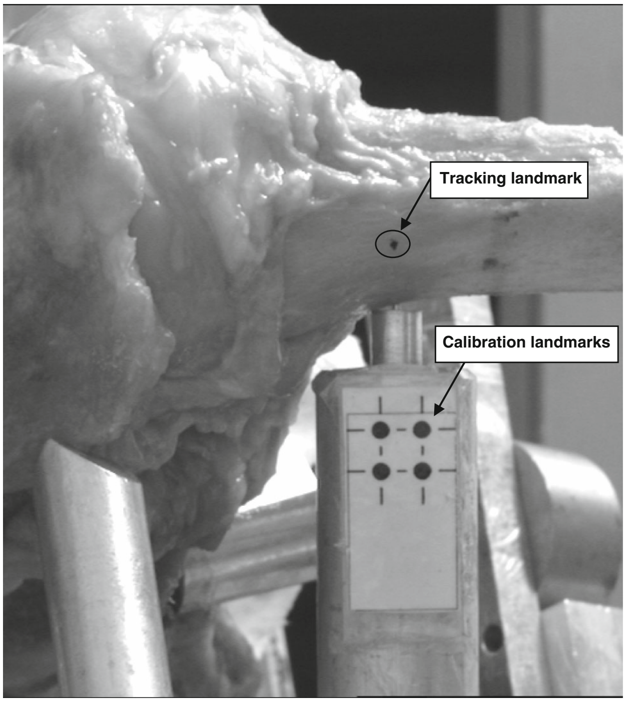

Fig. 2 View from the CCD camera measuring the postero-anterior displacement of the proximal humerus during loading. Landmarks were placed on the humerus and on the loading device for calibration purposes

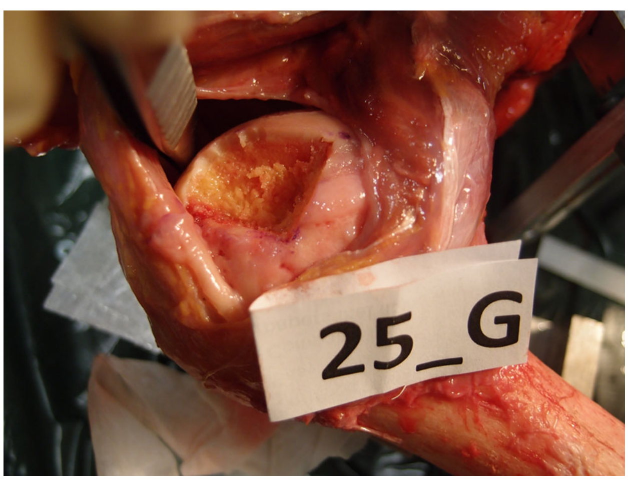

Fig. 3 Hill-Sachs lesion visualized through split between infraspinatus and teres minor

infraspinatus and teres minor muscles, we created a 2 cm × 2 cm × 0.5 cm (length × width × depth) Hill-Sachs lesion with small sharp bone cutter, starting from the uppermost portion of the humeral head and extending inferiorly and medially according to the TDM-scan study of Saito et al. [33] (Fig. 3). The two intervals were closed with Vicryl 2.0 sutures (Ethicon®, Somerville, NJ, USA), and the specimens were tested with the same protocol as with intact shoulders.

Third, randomly, one shoulder was repaired by a Bankart lesion anchor technique repair alone (Group B) using 2 double-loaded suture anchors (Twinfix® Ti 3.5 suture anchors, Smith & Nephew, Andover, MA, USA) and the contro-lateral shoulder of the same cadaver repaired by the same Bankart lesion repair technique and a posterior remplissage procedure (Group BW) with 2 double-loaded 5-mm anchors [20, 31]. (Twinfix® Ti 5.0 suture anchors, Smith & Nephew, Andover, MA, USA) The specimens were tested again with the same protocol.

The Bankart anchors were placed at 3.5 and 5 o'clock position, and the four sutures were used to repair the labrum.

The remplissage anchors were placed at the edge of the Hill-Sachs lesion close to the remaining cartilage level, and the double-pulley technique according to Koo et al. [20] was performed. In this technique, the two sutures of one anchor are linked with the two sutures of the other anchor in a double-pulley fashion creating a double mattress suture. Tying the knots of the sutures compresses the infraspinatus tendon on the bone bed of the Hill-Sachs lesion and using a mattress suture of this type is associated with less risk of muscle necrosis according to Koo et al. [20].

Humeral maximal external rotation was measured for intact specimens and after each surgical procedure before testing the specimens.

IRB approval is not required in our country for biomechanical cadaveric studies.

Statistical analysis

To compare the different states within the same group, the nonparametric Wilcoxon test was used. To compare results between the different groups, the nonparametric Mann–Whitney U test was used (MedCalc®, Mariakerke, Belgium). A post hoc power analysis was also performed. The statistical level of significance was set at $p < 0.050$ for all the tests. Data are reported as mean ± SD, with p values.

Results

Joint stiffness analysis (Table 1; Fig. 4)

In the Bankart group (Group B), joint stiffness was significantly lower in shoulders with Bankart and Hill-Sachs lesions compared with intact shoulders ($p = 0.015$) and to repaired shoulders ($p = 0.015$). But the repair did not restore normal stiffness as the stiffness of the repaired

Table 1 Mean values (standard deviations) of the analysed parameters

	Bankart repair			Bankart repair + remplissage		
	Intact	After lesion	After repair	Intact	After lesion	After repair
Joint stiffness (N/mm)	25.3 (11.6)	12.0 (4.4)	16.1 (4.7)	25.0 (7.8)	14.7 (4.6)	24.1 (6.9)
External rotation (°)	67.4 (12.6)	77.7 (11.8)	69.3 (9.6)	62.3 (12.1)	73.7 (12.1)	50.6 (8.1)

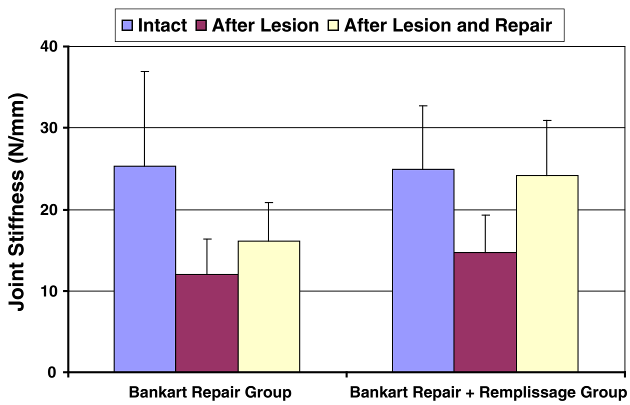

Fig. 4 Joint stiffness (mean and standard deviation) according to the testing configuration

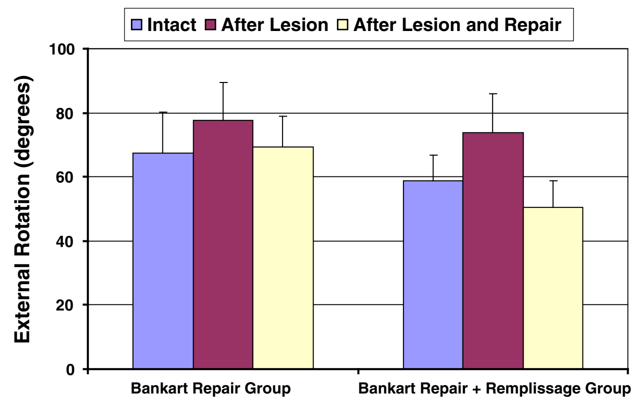

Fig. 5 Range of external rotation (mean and standard deviation) according to the testing configuration

shoulders was significantly lower than the one of the intact shoulders ($p = 0.047$).

In the Bankart + "Remplissage" group (Group BW), joint stiffness was significantly lower in the shoulders with Bankart and Hill-Sachs lesions compared with the intact shoulders ($p = 0.047$) and to the repaired shoulders ($p = 0.015$). The BW repair restored a joint stiffness close to the intact state, and there was no significant difference (n.s.) between the intact and the repaired shoulders.

No significant difference (n.s.) was found when comparing the two groups regarding the stiffness of both intact and injured shoulders.

The joint stiffness after repair was significantly higher in Group BW compared with the Group B ($p = 0.041$).

External rotation analysis (Table 1; Fig. 5)

In the Bankart group (Group B), the external rotation significantly increased after creation of the lesions ($p = 0.015$). After repair, it significantly decreased compared with the injured state and returned close to the intact values (n.s.).

In the Bankart + "remplissage" group (Group BW), the external rotation increased after the creation of the lesions ($p = 0.015$). It decreased after repair to a level lower than the one in the intact state ($p = 0.015$).

There was no statistical difference between the two groups regarding the external rotation of the intact shoulders and that of the injured ones (n.s.). The external rotation after repair was significantly different between the two groups ($p = 0.030$), with a loss of external rotation in the Group BW.

Discussion

The most important finding of the present biomechanical study is that adding the remplissage procedure increases shoulder stability compared with Bankart lesion repair alone, thus supporting our hypothesis.

Addressing the Hill-Sachs defect is still a matter of controversy in the literature as many techniques have been proposed with no consensus on the ideal one.

Recent studies have highlighted the preliminary good results of the remplissage technique initially described by Purchase et al. [31].

This technique is not technically demanding compared with arthroscopic Latarjet's procedure [22] and requires simple material with no risk of transmitted infection like bone allograft procedure [21] or secondary loosening or cartilage-metal long-term wear like partial head prosthetic resurfacing [18, 26].

However, clinical studies have a short-term follow-up which may be a problem to assess the final results of a shoulder stabilization technique as long-term studies on soft tissue techniques have shown decrease in good results with time [3, 6, 14, 19, 27–29, 31, 36, 39] particularly when the Bankart lesion is associated with glenoïd or humeral bone lesions [2, 4, 7, 25].

External rotation restriction has also been associated with this technique [10], but this fact remains controversial as some other series do not correlate decrease in external rotation with outcome [27] or show external rotation restriction, but with no clinical consequences [3].

In the present study, Bankart lesion repair associated with remplissage restored the joint stiffness to the initial value when Bankart lesion repair alone was not able to restore initial joint stiffness.

This fact is a partial biomechanical confirmation of the residual instability in some of the patients operated on with an isolated Bankart lesion repair when a Hill-Sachs lesion is associated [7–9, 12, 15]. It has been largely proven in clinical studies where the association of a Bankart and a bone lesion—glenoïd and/or humeral—may lead to as high as 89 % of shoulder instability recurrence after Bankart lesion repair alone [4, 25, 32, 35].

Very few biomechanical studies analysing the effect of the remplissage procedure after Bankart lesion and Hill-Sachs defect have been published. Only two recent publications, by the same team, have been found [13, 17]. Nevertheless, some differences could be found between these studies and the present one. Concerning the experimental protocol, the loading system was a mechanical testing machine and not an examiner contrary to these studies where the intra-observer variability in loading may increase the uncertainty in measurements. Moreover, in these studies, many tests were performed on the same shoulder. We feared that performing multiple tests on the same cadaveric shoulders might alter the biomechanical properties of the tissues. Hence, it was decided to randomize the study in two groups to have a comparative test with the smallest possible number of successive biomechanical tests on each cadaveric shoulder. Finally, the Hill-Sachs defects were different in these studies where two defects from two different sizes—15 and 30 % of humeral head—were simulated according to a previous biomechanical study [34]. In the present study, only one size of defect was simulated, but we chose to create a defect which might be closer to clinical reality simulating a Hill-Sachs lesion as close as possible from the lesion described in a recent computerized tomography analysis of Hill-Sachs lesion in anterior unstable patients by Saito et al. [33].

Despite these differences, Elkinson et al. [13] found results qualitatively close to the results of the present study in terms of stiffness, with restoration of a joint stiffness after Bankart lesion repair and remplissage close or even superior to intact joint.

In terms of external rotation, Bankart lesion and Hill-Sachs lesion increased external rotation of 10.3° (Group B) and 11.4° (Group BW) comparatively to intact joint. Although in Elkinson et al. study [13] the measured arc of rotation (internal plus external) was different from the one of the current study (only external), they also found an increase in internal–external range of motion after Bankart lesion. Another biomechanical study found a similar increase in external rotation with Bankart lesion compared with intact shoulder with an increase from 54.4° to 73.7° and a decrease after Bankart repair from 73.7° to 60.5° [24].

After Bankart lesion repair and remplissage, a 11.7° decrease in external rotation has been found compared with initial state. It can be considered, as Giles et al. [17] that this restriction may be due to the time-zero configuration of the biomechanical study and that in vivo external rotation may be recovered after physiotherapy and rehabilitation of the postoperative shoulder. Koo et al. [20] and Nourissat et al. [27] found no significant restriction of external rotation; Park and al. [28] did not evaluate external rotation with objective measurements, but none of their patients complained about loss of movement; Deutch et al. [10] found some residual external rotation restriction, but they described only one case; Boileau et al. [3] in the most recent published clinical study found 8° of external rotation restriction with the arm at the side and 9° with the arm at 90° of abduction, but with no clinical consequences.

The limits of the present study include those inherent to cadaveric studies where harvested tissues are from elderly subjects with different biomechanical properties from young living tissues. Another limit is that Hill-Sachs engaging mechanism could not be studied as no data were collected to detect dislocation. Moreover, the created Hill-Sachs lesions might be quite different from the Hill-Sachs lesions encountered in real pathological situations. However, design of the Hill-Sachs lesion was conducted to be large enough to allow engagement in physiological conditions.

Moreover, only one joint configuration (90° abduction with maximal external rotation) has been analysed. Finally, rotator cuff muscles and deltoid active forces have not been simulated as there is a controversy in the literature about the influence of forces developed by those muscles on shoulder stability [23, 37]. Nevertheless, the joint compressive force and the passive effect of the rotator cuff muscles were taken into account [34, 37].

Finally, the study was limited to seven pairs of shoulders. Despite this small number, many significant differences have been detected between the two surgical procedures, with post hoc powers between 53 and 95 %. But poor post hoc powers (lower than 16 %) were obtained when the differences were not significant, indicating a high risk of failing to detect a difference even if it might exist.

Despite those limitations, the present biomechanical study allowed to compare the two surgical procedures in the same experimental conditions.

Conclusion

The remplissage procedure associated with Bankart lesion repair was found to restore the joint initial stiffness in cadaveric shoulders with combined Bankart and Hill-Sachs lesions, whereas isolated Bankart lesion repair does not allow restoration of joint initial stiffness.

Our study confirms that a Bankart lesion repair alone is not able, at least biomechanically, to stabilize a shoulder with associated Bankart and Hill Sachs lesion to its initial normal parameters. Hence, a Hill-Sachs lesion remplissage might be a good solution to add immediate stability to operated unstable shoulders with associated Bankart and Hill-Sachs lesions.

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