The Effect of the Remplissage Procedure on Shoulder Range of Motion: A Cadaveric Study

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Purpose: The purpose of this in vitro biomechanical study was to assess the effects of the remplissage procedure for small- and large-sized Hill-Sachs lesions (HSLs) on shoulder range of motion (ROM) with a special interest in the apprehension position.

Methods: HSLs of 50% and 100% of the glenoid width were simulated in 7 cadaveric shoulders as small and large lesions, respectively, and the postoperative condition was reproduced by placing suture anchors on the articular surface and tying down the infraspinatus at the medial edge of the would-be lesion site. ROMs were measured in abduction, internal rotation, and external rotation with the humerus in the adducted and abducted position. In addition, the ROM was measured in the anterior apprehension position, in which 2 torques of external rotation and extension were applied simultaneously, and external rotation and horizontal extension ROMs were measured with the humerus in different abduction angles (20°, 40°, and 60°). Results: For standard ROMs, the procedure for the 50% HSL maintained complete ROMs, whereas the procedure for the 100% HSL significantly decreased external rotation ROM with the humerus in both the adducted and abducted positions, as well as abduction ROM. In the apprehension position, remplissage for the 50% HSL decreased extension ROM with the humerus abducted to 40° and 60°. Remplissage for the 100% HSL significantly decreased both external and extension ROMs regardless of the humeral abduction angle. Conclusions: In the cadaveric model with an intact humeral head and the simulated postoperative condition, the remplissage procedure for a large HSL caused significant restrictions in ROM of abduction in the scapular plane and external rotation with the humerus in both abduction and abduction. It also caused significant restrictions in both external rotation and extension ROMs in the apprehension position. Clinical Relevance: The indication for the remplissage procedure for the larger HSL should be considered carefully, especially for the competitive throwing athlete who needs exceptional external rotation ROM for optimal overhead throwing performance.

Posterolateral defects of the humeral head (Hill-Sachs lesions [HSLs]) are one of the most common findings in patients with recurrent anterior dislocations of the shoulder. It has been reported that the HSL is present in over 80% of recurrent instability cases.1-4 Many studies have investigated the effect of the HSL on recurrent glenohumeral instability and identified it as a contributor to anterior soft-tissue destabilization.1,4,5

The increased recognition of the HSL in recurrent instability highlights the need to better address the bone deficiency of the humeral head in addition to the arthroscopic Bankart repair (repair of the torn anterior glenoid labrum and capsule). Some procedures directly address the humeral head defect, whereas others manipulate the articular arc length, primarily by augmenting anterior and inferior glenoid bone to prevent engagement of the HSL. Engagement occurs when the arm is brought into a position of athletic function (defined as 90° of abduction combined with external rotation [ER] in the range between 0° and 135°).1 These solutions vary, including the Latarjet procedure,6,7 rotational humeral osteotomy,8 osteoarticular allograft transplantation,9 and transhumeral impaction bone grafting.10

In 2008 Wolf and colleagues11 described an arthroscopic method of filling the HSL by infraspinatus tenodesis


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and posterior capsulodesis, currently known as “re-
mlissage.” This technique has rapidly gained popu-
larlarity as an arthroscopic technique to manage large
HSLs, and although most clinical studies on the proce-
dure have found it to be successful,11-18 Deutsch and
Kroll19 reported 1 case of significant ER restriction af-
aer the remplissage procedure. This report led us to pay
attention to the possible restriction of shoulder range of
motion (ROM) after this procedure. In addition, there
had been no report on ROM in the shoulder anterior
apprehension test position. In this apprehension posi-
tion, the humerus tracks along a zone of contact known
as the glenoid track.20 We believe that the primary
stabilization feature of the remplissage procedure is that
the infraspinatus and joint capsule form a mechanical
block that contacts the glenoid rim at the glenoid track,
limiting the humeral head’s lateral translation. This
impediment to translation, however, may also lead to
a restriction of ROM.

The purpose of this in vitro biomechanical study was
to assess the effects of the remplissage procedure for
small- and large-sized HSLs on shoulder ROM with
a special interest in the apprehension position. We
hypothesized that the remplissage procedure would
decrease the ER ROM and the ROM in the apprehen-
sion position in a cadaveric model.

Methods
Preparation of Specimens
Seven fresh-frozen right cadaveric shoulders (4 male
and 3 female shoulders) from donors with a mean age
of 72 years (range, 58 to 83 years) at the time of death
were secured from our institution’s anatomic bequest
program. Specimens with a rotator cuff tear, joint
contracture, or radiographic evidence of glenohumeral
osteoarthritis were excluded. The shoulders were
thawed overnight at room temperature.

Each specimen was disarticulated at the scapulo-
thoracic joint proximally and transected at the middle
part of the humerus, distal to the deltoid muscle
attachment. To create precise anatomic coordinate
systems on the humerus, 2 reference points for the
medial and lateral epicondyles of the humerus were
obtained by drilling small (1 mm in diameter) holes at
the distal end of the humeral stump before each
humerus was cut. The skin, the subcutaneous tissues,
and all muscles except for the rotator cuff muscles were
removed. The joint was vented to atmospheric pressure
during the specimen preparation. A fiberglass rod was
inserted into the medullary canal of the humeral shaft
and cemented. The intramedullary rod and scapula
were secured on a custom-designed shoulder experi-
mental device (Fig 1).21,22

The shoulder experimental device allows the humerus
to be placed in a specified plane of abduction (e.g., the
scapular or coronal plane), angle of abduction, and angle
of humeral rotation (external or internal). Four sutures
were attached to the tendons of the subscapularis,
supraspinatus, infraspinatus, and teres minor muscles to
load the muscles with a weight-and-pulley system. A 22-
N total compressive force23 was applied across the gle-
nohumeral joint, divided between the subscapularis (10
N), supraspinatus (3.5 N), and infraspinatus/teres minor
(8.5 N) tendons. This force kept the humeral head
centered in the glenoid fossa. The magnitude and
distribution of the 22-N compressive force was deter-
mimed by the physiological cross-sectional area of each

Fig 1. (A) Custom-designed shoulder
experimental device. (B) The specimen
was secured to a Plexiglas plate on
a center column. Forces were applied to
each rotator cuff tendon using a pulley
system. One electromagnetic sensor
(2 arrowheads) was attached to the
humeral shaft, and the other sensor
(1 arrowhead) was attached to the
scapula. The source was attached to the
experimental device. The disk (arrow)
was attached to the intramedullary rod
and used to apply the rotational torques.
muscle. The specimen was kept moist with a spray of saline solution applied every 10 to 15 minutes during the test. Testing was performed at room temperature (24°C).

Definition of Shoulder Joint Coordinate System
The 6 degree of freedom electromagnetic tracking system (Polhemus, Colchester, VT) with accompanying MotionMonitor software (Innovative Sports Training, Chicago, IL) was used to measure the joint motion. Sensors were rigidly fixed to the scapula and humerus (Fig 1B), and anatomic coordinate systems were defined using a calibrated digitizing stylus attached to a sensor, as reported in a previous study. For the setup used in this study, the electromagnetic Polhemus system has a static accuracy of 0.8 mm and an angular accuracy of 0.15°. Anatomic coordinate systems were defined according to International Society of Biomechanics standards, with the humeral head center defined using a functional rotation approach.

Simulation of Remplissage Procedure
The initial approach to the glenohumeral joint consisted of a lesser tuberosity osteotomy (Fig 2A) that was used to access the posterior superolateral part of the humeral head. The osteotomy was fixed afterward on completion of the remplissage procedure simulation with 1 double-loaded 5.5-mm Corkscrew FT titanium suture anchor (Arthrex, Naples, FL) (Fig 2B). The effect of the osteotomy on shoulder motion was tested as a separate condition in the experimental protocol.

Fig 2. (A) The lesser tuberosity osteotomy was performed (arrowheads), and 1 double-loaded titanium suture anchor was inserted in the middle of the osteotomy plane (arrow). (B) The osteotomy was fixed with 1 double-loaded suture anchor on completion of the remplissage procedure simulation (arrows).
1 cm away from line CF and on the longitudinal lines of the 50% HSL and 100% HSL (Fig 3C). On the basis of pilot testing, the distance of 1 cm away from line CF was determined as the appropriate distance for both the 50% HSL and 100% HSL to create a secure bumper of infraspinatus at the critical engaging point on line CF where the defect reaches its greatest width. The accompanying sutures were passed through the posterior joint capsule and infraspinatus tendon by a horizontal mattress technique and then tied on the subdeltoid side of the rotator cuff.

**Test Conditions**

The testing protocol was designed to study the effects of the remplissage procedure on glenohumeral ROM. The following shoulder conditions were tested: (1) intact, (2) repaired osteotomy of the lesser tuberosity, (3) remplissage procedure for the 50% HSL, and (4) remplissage procedure for the 100% HSL.

**Motion Measurements**

Standard ROMs were measured in abduction in the scapular plane (Fig 4A), internal rotation (IR) and ER with the humerus in the adducted position (0° of abduction), and IR and ER with the humerus in 60° of glenohumeral abduction (simulating 90° of humerothoracic abduction) (Fig 4B). In addition, a series of ROMs was also measured in the directions of ER and horizontal extension with the humerus placed in 20°, 40°, and 60° of glenohumeral abduction (Fig 4C), simulating 30°, 60°, and 90° of humerothoracic abduction, respectively, in the apprehension position. This series of ROMs is different from the former standard ROMs in that 2 torques of both ER and horizontal extension were applied simultaneously while the ROMs were measured in ER and horizontal extension. This apprehension condition was selected because it is a provocative position for engagement of the HSL and subsequent redislocation of the shoulder. ROM was measured with the electromagnetic tracking system while a set torque was applied to the humerus through the distal end of the intramedullary rod (for abduction and horizontal extension) or a disc (Fig 1B) attached to the rod (for IR and ER). The torque was determined by use of a force transducer and moment-arm measures from the axes of rotation to the point of force application. The end-ROM torques were 250 N-mm for IR and ER, 600 N-mm for horizontal extension, and 800 N-mm for abduction, as described in previous studies.

**Conversion of Size of HSL to Its Equivalent in Other Methods**

This study quantified the size of the HSL relative to the glenoid, whereas previous studies used different measurements to describe its size. Sekiya et al. described the defect size as a percentage of the humeral head diameter. Cho et al. described the defect size as the linear distance of the width between 2 edges of the lesion measured along line CF (Fig 3C) and expressed as a percentage of the humeral head diameter. Our study took the necessary anatomic measurements so that the lesion sizes were described both relative to the glenoid and relative to the humeral head so that comparisons with the methods described earlier could be made.
Data Analyses
Statistical analysis was performed with JMP 10.0 software (SAS Institute, Cary, NC). A repeated-measures analysis of variance was run individually on the ROM data for each arm position. The sphericity assumption was tested by use of the Mauchly sphericity test, and in the cases in which the Mauchly test was significant, a Huynh-Feldt correction was used. For the arm positions showing a significant difference in ROM between surgical conditions, a pair-wise repeated-measures analysis was run with proper corrections made to the α level. For all analyses, the significance level was set at α = .05. Sample size calculation was performed based on ROM in degrees as the primary outcome. With 7 cadaveric shoulders, there was 80% power to detect a difference of 14° in mean ROMs between the conditions.

Results
Comparison of Different Definitions for Size of HSL
The defect sizes of the 50% HSL and 100% HSL in our study were 9.9% ± 1.4% and 39.6% ± 5.6% of the humeral head diameter as described by Sekiya et al.\textsuperscript{33} With the method of Cho et al.,\textsuperscript{31} the defect sizes were 31.4% ± 2.2% and 62.8% ± 4.5%, respectively.

Validation of Lesser Tuberosity Osteotomy
There were no statistically significant differences in the ROM between the intact and osteotomy conditions for any arm position with the exception of the ER ROM with the humerus abducted. This position showed a 4° increase in the ER ROM (Figs 5 and 6). Given that 10 of the 11 arm positions tested showed no ROM differences between the intact and osteotomy conditions, and that the single condition showing a statistically significant difference was arguably clinically significant at 4°, the assumption that the osteotomy did affect the ROM is considered validated.

Standard ROM
The remplissage procedure for the 50% HSL and 100% HSL decreased the abduction ROM from 84.3° ± 9.0° (mean ± standard deviation) in the intact condition to 73.4° ± 15.3° and 66.0° ± 12.0°, respectively. The 100% HSL condition decreased relative to both the intact and osteotomy conditions at a statistically
significant level ($P < .05$). The procedure for the 50% HSL decreased the mean ER ROM in both the adducted and abducted positions to $68.6^\circ \pm 16.6^\circ$ and $83.3^\circ \pm 15.8^\circ$, respectively, which were not statistically different from the intact condition ($73.5^\circ \pm 19.8^\circ$ and $93.1^\circ \pm 7.0^\circ$, respectively). However, the procedure for the 100% HSL decreased ER ROM in the adducted and abducted positions to $47.2^\circ \pm 18.9^\circ$ and $56.9^\circ \pm 22.2^\circ$, respectively, which were statistically different from the intact, osteotomy, and 50% HSL conditions in their respective arm positions (except for the intact adducted position). No statistically significant differences were found in IR ROM (Fig 5).

**ROM in Apprehension Position**

For ER, the ROM of the intact condition was $80.0^\circ \pm 12.1^\circ$ ($20^\circ$ of abduction), $79.2^\circ \pm 12.0^\circ$ ($40^\circ$ of abduction), and $73.8^\circ \pm 10.3^\circ$ ($60^\circ$ of abduction). There was no statistically significant difference between the intact and 50% HSL conditions in any abduction angle. However, the 100% HSL condition decreased ER ROM to $32.8^\circ \pm 15.2^\circ$ ($20^\circ$ of abduction), $32.3^\circ \pm 15.7^\circ$ ($40^\circ$ of abduction), and $34.8^\circ \pm 11.9^\circ$ ($60^\circ$ of abduction). Compared with the intact condition, these changes were statistically significantly different at $P < .05$ in $20^\circ$ and $60^\circ$ of abduction and at $P = .058$ in $40^\circ$ of abduction (Fig 6A).

For extension, the ROM of the intact condition was $26.4^\circ \pm 10.0^\circ$ ($20^\circ$ of abduction), $30.7^\circ \pm 6.6^\circ$ ($40^\circ$ of abduction), and $31.1^\circ \pm 5.6^\circ$ ($60^\circ$ of abduction). Compared with the intact condition, the 100% HSL condition decreased the ROM to $4.0^\circ \pm 3.6^\circ$ ($20^\circ$ of abduction), $-2.2^\circ \pm 3.9^\circ$ ($40^\circ$ of abduction), and $-6.3^\circ \pm 5.6^\circ$ ($60^\circ$ of abduction). These changes were statistically significantly different at $P < .05$ in $40^\circ$ and $60^\circ$ of abduction and at $P = .10$ in $20^\circ$ of abduction. The negative values, in this case, indicate that the angle was anterior to the scapular plane. In addition, the 50% HSL condition showed a statistically significant decrease in horizontal extension with the humerus in $40^\circ$ and $60^\circ$ of abduction ($11.7^\circ \pm 10.2^\circ$ and $8.2^\circ \pm 5.9^\circ$, respectively) (Fig 6B).

**Discussion**

When one reviews the results of our study, it is evident that in the cadaveric model with an intact humeral head and the simulated postoperative condition, the remplissage procedure restricts the ROM of the glenohumeral joint in several planes of motion, with procedures on large HSLs having the most adverse effects. The ROM after the repair of the 100% HSL was decreased in abduction, all conditions of ER, and all conditions of horizontal extension. The IR ROM appears to be unaffected by the remplissage procedure, with little to no difference between the intact and postoperative procedures. As we expected, the ROM in the apprehension position decreased dramatically after the remplissage procedure for the 100% HSL in both ER and extension regardless of the humeral abduction angle. In addition, the procedure for the 50% HSL, the smaller lesion, showed notable restrictive effects on the horizontal extension ROM with the humerus in the apprehension position. The decrease in abduction ROM was unexpected because it has never been previously reported clinically or through in vitro study. Had this result been expected, the study protocol would have been slightly different to include abduction ROM testing in a variety of planes. Although the largest abduction difference identified was less than $20^\circ$, this new finding should be noted as a topic needing further study.

There have been several methods reported to describe the size of the HSL, with no clear consensus...
about the best method to use. Our study used the
glenoid track concept introduced by Yamamoto et al.\textsuperscript{20}
This method enables the simultaneous evaluation of
the relation between the HSL and the glenoid in the
search for the engagement of the HSL onto the anterior
glenoid rim. It also enables the evaluation of the defect
size during arthroscopic surgery. The 2 lesion sizes in
our study differ by a factor of 2, whereas the same
lesions expressed in the method of Sekiya et al.\textsuperscript{33} would
differ by a factor of 4. The reason for this discrepancy
is that in the method of Sekiya et al., the lesion is
measured by looking directly at the humeral head
articular surface in a single view, regardless of the size
and location of the lesion. A future study could be
performed to determine the most effective method to
describe the size of engaging HSLs.

In this study, as we explained in the summary pre-
presented earlier, we found that the remplissage procedure
for the large HSL, the 100\% HSL, significantly decreased the ER ROM with the humerus in both the
adducted and abducted positions. The first in vitro study
about the remplissage procedure was recently reported
by Giles et al.\textsuperscript{32} Our results for ROM differed from
theirs, although their main concern was the difference
in stability and ROM restriction between the remplis-
sage procedure and other procedures for the engaging
HSL (i.e., humeral head allograft and partial resurfacing
arthroplasty). The motions tested in their study
included internal-external ROM with the humerus in
either the adducted or abducted position, as well as
horizontal extension. Among these motions, the only
significant loss in ROM relative to the intact condition
was found in internal-external ROM with the humerus
in the adducted position after the remplissage proce-
dure on a 30\% HSL (sized relative to the humeral head
diameter) rather than the larger 45\% lesion, for
unknown reasons. Moreover, the difference in ROM
between them was about 15\%. There are 2 important
factors to consider when comparing our results with
those of Giles et al. First, Giles et al. defined the size of
the HSL relative to the humeral head diameter,
wheras we defined it relative to the glenoid width.
Hence an HSL of 100\% of the glenoid width used in our
study is equivalent to an HSL of 40\% of the humeral head
diameter as described in the beginning of the
“Results” section, which falls between the 30\% and
45\% Hill-Sachs defects used by Giles et al., making it
difficult to compare our results with theirs directly.
Second, because Giles et al. did not report the IR and ER
separately, it cannot be determined whether the
reduction in ROM seen in their study was due to the ER
restriction, as was found in our study. If an assumption
of restricted ER ROM is made in the study of Giles et al.,
their finding of a decrease in IR/ER only in the
adducted position after remplissage on the smaller
defect still appears to be different from our results, in
which the ER decreased significantly between the intact
and 100\% HSL conditions in both the adduction and
abduction positions and the procedure for the larger
lesion had an even more significant negative effect on
ER ROM. In addition, the same can be said for the other
report from the same group, in which the IR/ER ROMs
were significantly restricted only in the adducted posi-
tion relative to the intact condition after the procedure
for both 15\% HSL and 30\% HSL.\textsuperscript{34}

One reason for the difference in the abducted
position is that we performed the procedure differently. We
placed anchors on the articular surface at the antici-
pated location of the medial edge of the lesion to create
the soft-tissue bumper, as it was called in the articles
mentioned previously.\textsuperscript{32,34} As was shown by magnetic
resonance imaging in a previous article reported by
Nourissat et al.,\textsuperscript{15} the Hill-Sachs defect is supposed to be
filled with the ingrowth of the inset infraspinatus
and posterosuperior capsule after a biological healing
process. The expected postoperative state of the
procedure is depicted in Fig 7A. In our cadaveric model,
if we followed the original description of this procedure
and placed the anchors into the valley of the defect, we
may have encountered the condition depicted in
Fig 7B, in which the glenoid traveled beyond the medial
edge of the defect because of the lack of a mechanical
block, the essential stabilizing mechanism of this
procedure, which is supposed to exist after the
completion of this procedure with biological healing.
Fearing such a situation, we fixed the anchors on the
articular surface at the medial edge of each imaginary
HSL without creating the actual defect (Fig 7C) to
obtain the mechanical block. We believe that our model
simulated a more realistic postoperative condition of
the remplissage procedure and the ROM restriction in
ER with the humerus in abduction would be an accu-
rate consequence.

The remplissage procedure is a minimally invasive
approach to convert an intra-articular HSL, which
would engage and cause a failed stabilization surgery,
into an extra-articular lesion, without the morbidity
associated with open procedures and additional graft
material, making the procedure quick and easy to
perform. With interest in the remplissage procedure
increasing, several reports on the clinical results of the
procedure have recently been published,\textsuperscript{12-19} after the
original report of Purchase et al.\textsuperscript{11} In these reports,
except for a case reported by Deutsch and Kroll,\textsuperscript{19}
no problems with decreased ROM, including ER, were
reported. However, we noticed that the ROM with the
shoulder in the apprehension position, considered the
position of athletic function by Burkhart and De Beer,\textsuperscript{1}
in which the engaging HSL was first found and diag-
nosed, had not been specifically addressed. This posi-
tion was of concern because after the completion of the
remplissage procedure, the path of the glenoid with the
arm in the apprehension position, which was termed the glenoid track by Yamamoto et al., is filled with and closed by the inset infraspinatus tendon and joint capsule, causing the glenoid to travel around the lesion medially and possibly leading to ROM restriction of the glenohumeral joint. As described in the “Results” section, in the shoulder apprehension position, the procedure for smaller lesions (50% HSL) decreased extension with the humerus in 40° and 60° of abduction. Furthermore, the procedure for the larger lesion (100% HSL) caused even more significant restriction in both ER and extension compared with the intact condition. According to Burkhart, pitchers participating in high-level sports activities maximize their shoulder rotational arc by hyper-external rotation in the late cocking phase of throwing to throw a fastball. Therefore it is of particular concern to us that the reduction in ER in this position may have a negative effect on the performance of those throwing athletes. This new finding will bring renewed attention to the possible ROM restriction of the shoulder in the apprehension position after this procedure.

**Limitations**

There are some limitations in this study. First, there was a lack of information regarding the medical history or any symptoms of the shoulder joint of the cadavers. We may not be able to say that the cadaveric shoulders were completely normal; however, the shoulders were screened using macroscopic and radiologic examinations before testing. Second, the specimens used in this study were from elderly donors, whereas the remplissage procedure is typically performed in young patients. Third, we performed a lesser tuberosity osteotomy to expose the posterosuperior part of the humeral head and reproduce the identical HSL accurately across the different specimens, whereas the actual procedure is performed solely with arthroscopy. We did our best to repair the lesser tuberosity osteotomy and the soft tissue around it. As described in the “Results” section, there was only 1 arm position (ER with the humerus in the abducted position) in which a statistically significant difference was observed between the intact condition and the condition after the osteotomy repair. However the difference on average between them was 4°, and we believe that the osteotomy had minimal effect on the subsequent results of the remplissage procedure. Fourth, although the remplissage procedure is generally performed in addition to Bankart repair (repair of the torn anterior glenoid labrum and capsule), we intentionally did not create a Bankart lesion. This is because the primary objective was to investigate the effect on shoulder ROM that is inherent to the remplissage procedure and including a Bankart lesion may have had confounding effects. Fifth, we did not create a Hill-Sachs defect. Instead, we created the infraspinatus footprint using suture anchors on the articular surface at the medial edge of the imaginary lesion because this best replicates the medial shift of the infraspinatus attachment after remplissage. However, by using intact humeral heads, we could have missed the other effects of the procedure on ROM. For example, had the infraspinatus been pulled into the defect, its tension would have been increased and the posterior joint capsule would have become tighter, which seems to be related to other ROM restrictions to IR. Sixth, the
results obtained represent the condition immediately after the completion of the remplissage procedure. Therefore the long-term effects of this procedure in vivo might be different.

Conclusions
In the cadaveric model with an intact humeral head and the simulated postoperative condition, the remplissage procedure for a large HSL caused significant restrictions in ROM of abduction in the scapular plane and ER with the humerus in both abduction and abduction. It also caused significant restrictions in both ER and extension ROMs in the apprehension position.

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