ORIGINAL ARTICLE

Arthroscopic dynamic analysis of scapular notching in reverse shoulder arthroplasty

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KEYWORDS
Reverse shoulder arthroplasty; Scapular notching; Shoulder arthroplasty instability

Summary

Introduction: Despite the success of reverse shoulder arthroplasty, the rate of scapular notching phenomena is high and represents a significant risk of glenoid prosthetic component loosening over the long term. The aim of this study was to perform an arthroscopic dynamic analysis of the impingement of the humeral cup on the neck of the scapula in order to highlight the causes of the occurrence of this notch and possible ways to avoid it.

Materials and methods: The SMR reverse shoulder prosthesis (Lima\textsuperscript{a}) was successively implanted in 11 shoulders of seven cadavers. Three glenospheres (36 mm, 36 mm with a 4-mm lowering offset, and 44 mm) were consecutively tested on each shoulder. An arthroscopic study was then performed in each case looking for scapular notching depending on the position of the shoulder, its exact location, and any resulting prosthetic instability. Rates of notching for each glenosphere in the different shoulder positions were compared.

Results: For each glenosphere, the highest rates of notching were recorded in the zero abduction position. Increasing abduction reduced the rates of notching and prosthetic instability for all types of glenosphere. External rotation increased both risks with 36-mm glenospheres but reduced them with the 44-mm glenosphere. The lower center of rotation, thus, reduced the risk of notching but increased the risk of instability associated with it. Increasing the prosthetic diameter reduced both risks.

Conclusion: Reducing the risk of scapular notching and prosthetic instability requires, in addition to a lower center of rotation, the use of glenosphere diameters greater than 36 mm. The use of a humeral cup with a posteroinferior indentation should also contribute to reducing this risk.

Level of evidence: Level IV.

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Introduction

In the 1980s, the modest benefits obtained with standard and anatomic shoulder prostheses in omarthritis associated with unrepairable rupture of the rotator cuff led to searching for ways to improve the functional results. Paul Grammont demonstrated the importance of the center of rotation position and sought to compensate for the deficient rotator cuff with optimal use of the deltoid muscle, the only remaining motor function muscle of the shoulder. In absence of rotator cuff muscles, intrinsic rebalancing of the middle deltoid reinforced its abduction component. The reverse shoulder prosthesis makes it possible to overcome elimination of supraspinatus muscle activity by medializing the center of the glenohumeral joint and increasing the lever arm of the deltoid [1,2].

After this success and subsequent innovations, notably the positive effect of lowering the center of rotation in addition to medialization, several complications remain to be resolved, in particular scapular notching, involving the superolateral part of the pillar of the inferior edge of the scapular neck, the main source of clinical failure and surgical revision.

The objective of this study was to demonstrate the causes of scapular notching occurrence and the means to prevent it, by carrying out an arthroscopic dynamic analysis of the contact of the humeral cup on the scapular neck.

Material and methods

This cadaver study was conducted in the Anatomy Laboratory of the Rouen Faculty of Medicine and Pharmacy. The SMR reverse shoulder prosthesis (Lima®) (Fig. 1) was successively implanted in 11 shoulders of seven cadaver subjects. An arthroscopic analysis was then performed in each case, searching for scapular notching, its exact location, and the existence of any resulting implant instability. The choice of this prosthesis was based on the modularity of the glenosphere (four models were available).

The cadaver was installed in the sitting position. AMartini approach was used, allowing the distal insertion of the deltoid muscle to be raised with its bony insertion. The glenohumeral joint was then exposed, after resection of the residual rotator cuff if necessary (supraspinatus and infraspinatus). The subcapsular tendon was preserved. The humeral and then glenoid implants were placed by the same operator using the ancillary instrumentation in a similar fashion in all cases so as to ensure reliable and optimal comparison of the different observations.

The humeral head was perforated at its summit using a square nail, then the intramedullary reamer was inserted until the cutting guide touched the anatomic neck. This was attached using four 2-mm Kirschner wires with in all cases a 20°-retroversion adjusted in relation to the forearm. The osteotomy of the humeral head was performed using an oscillating saw with a 150°-inclination in relation to the diaphyseal axis. The humeral stem was not cemented. The glenoid was then exposed using a Fukuda retractor positioned at its lower pole resting on the protector of the humeral cut. The center of the glenoid was defined by the intersection between its vertical and horizontal axes. The guide pin was inserted along the vertical axis, so that the metaglene was flush with the inferior pole of the glenoid. The wire was inserted horizontally, perpendicular to the glenoid, so that no inferior tilt or superior tilt resulted. Similarly, no retroversion or anteversion was given to the glenoid implant. The glenoid peg was fashioned with a specific cannulated drill positioned on the guidewire, then the cartilage was resected to the subchondral bone using the glenoid reamer. The metallic metaglene (Fig. 2), shaped like a convex capsule, contrary to the flat baseplate of the Grammont implant, was adapted to the normal curve of the bony glenoid. It was fixed in the bone with a central peg held in place with the press-fit technique with two additional screws. The glenosphere was fixed on the metaglene by impaction of the Morse cone.

Three Lima glenospheres (36 mm, 36 mm with 4 mm inferior off-centering, and 44 mm) were successively placed on the metaglene, fixed with screws, and tested on the 11 shoulders. The glenospheres had been marked beforehand with an engraved clockwise marking for the right shoulders and a counterclockwise marking for the left shoulders.

Figure 1 Lima SMR reverse prosthesis.

Figure 2 Lima metaglene convexity, contrary to the flat baseplate of the Grammont prosthesis.
so as to visualize the locations of scapular notching and subluxation arthroscopically.

After reduction of the implant, the deltoid was reinserted impermeably to facilitate retention of arthroscopic saline solution. Its earlier disinsertion with a humeral bone plug at the deltoid V provided solid bone fixation using a screw and two Hoffmann external fixation pins.

Two arthroscopic approaches were used: a classic posterior approach and a low anterior approach through the subscapular tendon, at the base of the acromioclavicular joint. For the three Lima glenospheres, eight positions were studied: 0° abduction for successive external rotation of 0° (ER 0°) and 30° (ER 30°), and 0, 30, and 60° abduction for external rotations of 30 and 60° (ER 30°, ER 60°). The presence of scapular notching and any resulting subluxation were sought as well as the location on the glenospheres using the engraved marking. Subluxation was defined by visualization of a beginning of humeral cup dislocation in relation to the glenosphere. The data for each shoulder were collected on an Excel double-entry spreadsheet: the position of the shoulder in abduction and external rotation noted in the spreadsheet rows and the existence of notching or subluxation noted in the spreadsheet columns.

Each arthroscopy was digitized using Pinacle® software and recorded on a hard disk.

The notching rate for each glenosphere in the different shoulder positions was compared using an exact test based on the binomial law on matched series, equivalent to the McNemar test. A difference between two glenospheres was deemed significant when the p-value was less than 0.05.

### Results

Eight positions for each of the three Lima glenospheres were studied on 11 shoulders, i.e., 88 arthroscopic observations for each of the three Lima glenospheres for a total of 264 observations. This allowed us to analyze implant centering and stability in relation to the type of glenosphere used as well as the abduction position and external rotation.

#### 36-mm glenosphere (Table 1)

<table>
<thead>
<tr>
<th>36-mm standard</th>
<th>Abduction</th>
<th>External rotation</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0°</td>
<td>30°</td>
<td>60°</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0°</td>
<td>3S (6.8 h)</td>
<td>11 N</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>30°</td>
<td>8N (7.5 h)</td>
<td>6N</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>60°</td>
<td>2N (7.8 h)</td>
<td>6N</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>21 N / 33</td>
<td></td>
</tr>
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<td></td>
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</tbody>
</table>

N: notching; S: subluxation. Number of notches (glenoid notching) and subluxations.

In zero abduction, scapular notching was observed systematically. This was for the most part inferior, at a mean 6.8 h (range, 5—8 h). Increasing abduction progressively reduced the number of inferior notches for all external rotation values. Of the 11 shoulders in zero ER, 11 cases of notching were observed in 0° abduction, eight in 30° abduction, and two in 60° abduction.

Notching progressively became posteroinferior with abduction (6.8 h in 0° abduction, 7.8 h in 60° abduction).

External rotation increased the risk of notching: 63.6% (21/33) in 0° ER, 69.7% (23/33) in 30° ER, and 86.4% (19/22) in 60° ER. In the extreme position (abduction 60°, external rotation 60°), notching was observed systematically.

Abduction improved implant stability by decreasing the number of subluxations caused by notching, whereas external rotation increased it. In 60° external rotation, notching systematically caused implant subluxation, whatever the degree of abduction.

#### 36-mm eccentric glenosphere (Table 2)

The 36-mm eccentric glenosphere significantly reduced the overall rate of notching compared to the standard glenosphere, which decreased from 71.5 to 43.2% (P < 0.00005). However, if notching was present, the overall rate of subluxation was higher than that of the standard glenosphere (76.3% versus 47.6%).

Placing the shoulder in abduction clearly improved centering: in all of the observations with this glenosphere, the notching rate decreased from 68.2% (15/22) in zero abduction to 42.4% (14/33) in 30° abduction and to 27.3% (9/33) in 60° abduction.

External rotation increased the notching rate: when the shoulder was in 60° abduction, the notching rate increased from 1/11 (9.1%) in 0° ER to 6/11 (54.5%) in 60° ER. The risk of notching with external rotation was lower than the risk with the standard glenosphere, although non significantly: in maximum external rotation, whatever the degree of abduction, the notching rate decreased from 86.4% (19/22) with the standard glenosphere to 63.6% (14/22) with the eccentric glenosphere.

The 36-mm eccentric glenosphere shifted the notching to a more posterior location in the glenoid compared to the standard glenosphere. For example, of the eight notches observed in 30° abduction/60° ER with the two types of...
Table 2 36-mm eccentric glenosphere.

<table>
<thead>
<tr>
<th>Abduction</th>
<th>External rotation</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0°</td>
<td>30°</td>
</tr>
<tr>
<td>0°</td>
<td>7 N (7.1 h)</td>
<td>3 N (7.5 h)</td>
</tr>
<tr>
<td></td>
<td>8 N (7.25 h)</td>
<td>8 N (7.6 h)</td>
</tr>
<tr>
<td>30°</td>
<td>1 S</td>
<td>1 S</td>
</tr>
<tr>
<td>60°</td>
<td>6 S</td>
<td>6 S</td>
</tr>
</tbody>
</table>

Number of notches (glenoid notching) and subluxations.

Table 3 44-mm glenosphere.

<table>
<thead>
<tr>
<th>Abduction</th>
<th>External rotation</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0°</td>
<td>30°</td>
</tr>
<tr>
<td>0°</td>
<td>8 N (6.7 h)</td>
<td>7 N (7.4 h)</td>
</tr>
<tr>
<td></td>
<td>2 S</td>
<td>3 S</td>
</tr>
<tr>
<td>30°</td>
<td>3 N (7.3 h)</td>
<td>3 N (7.3 h)</td>
</tr>
<tr>
<td></td>
<td>0 S</td>
<td>0 S</td>
</tr>
<tr>
<td>60°</td>
<td>2 N (8 h)</td>
<td>1 N (6 h)</td>
</tr>
<tr>
<td></td>
<td>0 S</td>
<td>0 S</td>
</tr>
<tr>
<td>Total</td>
<td>13 N / 33</td>
<td>14 N / 22</td>
</tr>
</tbody>
</table>

Number of notches (glenoid notching) and subluxations.

glenosphere, the mean location was at 7.6 h with the standard glenosphere and 8 h with the eccentric glenosphere. In 60° abduction, the only impingement in 0° ER with the eccentric glenosphere was located at 9.5 h and the two notches in 30° ER at a mean 9 h.

44-mm glenosphere (Table 3)

The 44-mm glenosphere significantly reduced the notching rate compared to the two 36-mm glenospheres. The risk was reduced by nearly half compared to the standard 36-mm glenosphere ($P < 0.000001$), decreasing from 71.6% of the 88 observations with the 36-mm standard glenosphere to 35.2% with the 44-mm glenosphere. Most particularly, in 60° abduction, the risk decreased from 57.6% (19/33) to 12.1% (4/33) ($P < 0.0005$). The risk of instability in cases of notching was 25.8% of all the observations, for a significant improvement compared to the two 36-mm glenospheres ($P < 0.000001$).

Similar to the 36-mm glenospheres, placing the shoulder in abduction had a centering effect: the notching rate decreased from 68.2% (15/22) in 0° abduction to 12.1% (4/33) in 60° abduction.

Contrary to the 36-mm glenospheres, external rotation also improved centering: from 39.4% (13/33) of the notches in 0° ER, this was reduced to 33.3% (11/33) in 30° ER and to 31.8% (7/22) in 60° ER.

Discussion

The clinical results of total reverse shoulder arthroplasty in the treatment of omarthritis associated with unreparable rupture of the rotator cuff [3–6] and, more recently, complex fractures of the proximal humerus [7–10] are encouraging, notably in terms of pain and function. However, the causes of the occurrence of scapular notching, often observed on X-rays in the early postoperative months, remain partially unexplained. Nérot’s [11] radiographic classification makes it possible to assess the potential for progression. The notching rates reported vary: none for Cuff et al. [12] and Frankie et al. [13], 24% for Young et al. [14], 56% for Valenti et al. [11], 62% for Lévigne et al. [15], 63% for Boulahia et al. [16], 65% for Sirveaux et al. [3], 74% for Boileau et al. [17,18], and 96% for Werner et al. [6]. In particular, out of 49 SMR (Lima®) implants revised at a mean follow-up of 38 months, Young et al. [14] found 24% inferior notches (12 cases). They measured less than 5 mm in all cases and never reached the inferior glenoid screw. No humeral or glenoid loosening was observed at the last follow-up, but the mean clinical results were inferior in patients who presented notching, although this result was not
statistically significant. In six patients in whom an eccentric glenosphere was implanted, no notching was found. In the present study, the eccentric glenosphere reduced the rate of humeral notching by 28.4% of all the arthroscopic observations, a significant difference compared to the standard glenosphere.

Scapular notching can be the cause of radiographic modifications in the bone–implant interface in the humerus or the glenoid [15] and sometimes clinical function deterioration [19]. Lévigne et al. [15], who noted 62% notching at 47 months of follow-up in 337 patients, found a significant association with the presence of glenoid and humeral periprosthetic radiolucency, despite the absence of clinical signs. Sixty-eight percent of these notches were visualized early at 1 year of follow-up. Of 77 Delta III implants revised at a mean 44 months of follow-up, Simovitch et al. [19] found posterior notching in 44% of the cases, inferior in 30% of the cases, and anterior in 8%. Inferior notching was identified after a mean 4.5 months and never appeared beyond the 14th month. The size of the notch was significantly inversely correlated with the final Constant score. For Boileau et al. [18], who found 74% scapular notching at 50 months in 40 patients, there was a significant relation with the approach used, in favor of the deltopectoral approach compared to the anterosuperior approach. This seems to be related to the greater ease of positioning the glenoid implant inferiorly via the deltopectoral approach. However, there was no significant relation between the presence of a notch and the final Constant score.

The arthroscopic analysis of the intra-articular behavior of the SMR reversed shoulder implant has visually demonstrated the contact between the humeral implant and the postero-inferior part of the scapular neck as well as the superolateral part of the scapular pillar, the source of the notching. The absence of deltoid muscle tone and its role in implant centering and stability through glenohumeral subluxation was a limit in this study. Bone reinsertion of the deltoid and its humerus insertion after implantation nonetheless allowed us to simulate, at least partially, its action. Scapulothoracic movements in abduction, clinically difficult to quantify, were also reduced on the cadaver.

Use of the standard 36-mm glenosphere implanted flush with the inferior pole of the glenoid showed constant inferior contact in the neutral position (0° abduction, 0° ER), which decreased and progressively became posteroinferior with abduction. External rotation progressively increased postero-inferior notching. Lowering the rotational center by 4 mm with the eccentric 36-mm glenosphere and increasing the implant diameter with the 44-mm glenosphere significantly reduced the impingement rate. The risk of implant instability associated with notching was increased by placing the rotational center lower, whereas it was reduced with the increase in glenosphere diameter. Many other experimental studies have shown the value of lowering the center of rotation and increasing the glenosphere diameter; Chou et al. [20], in a study on dry bones testing, four SMR glenosphere models (standard and inferior eccentric 36 mm, standard and eccentric 44 mm); Gutierrez et al. [21], in another study on dry bones testing, three glenospheres with different diameters (30, 36, and 42 mm) in three different glenoid positions (superior, central, and inferior); in a cadaver study; Nyffeler et al. [22] showed that the placement of the metaglene 2–4 mm under the lower edge of the glenoid significantly reduced the risk of scapular notching; in a computer-assisted 3D modeling study of the Delta III implant (Depuy®), Kontaxis and Johnson [23] demonstrated the complete disappearance of all notching beginning with 6 mm of lowering, with a risk, however, of instability due to an excessively low position of the inferior screw within insufficient bone stock; in another study on a digital model, Gutierrez et al. [24] ranked the importance of the parameters providing optimal joint range of motion without impingement: lateralization of the center of rotation was the most important parameter, along with inferior positioning of the glenosphere, its inferior tilt, the neck angle of the humeral component, and prosthetic size. Lateralization and lowering the center of rotation also improved the joint range of motion, in particular in abduction-adduction [19,22].

The results of these experimental models in terms of these parameters’ importance and their being taken into account during implantation have been confirmed by many clinical studies. Cuff et al. [12] found no notching with 96 prostheses after a mean 27.5 months, as a result of 6–10 mm lateralization of the rotational center associated with a slight inferior tilt of the metaglene. Frankie et al. [13] observed no notching in 60 patients reviewed at a mean 33 months, using a glenosphere model including lateralization of the center of rotation, with, however, 23.3% revision for glenoid loosening [25]. Of the 14 revisions in Holcomb et al.’s initial series [25], a glenosphere with a larger diameter than the replaced implant was placed in 11 cases, providing optimal prosthetic stability. No scapular notching was found in the 14 cases at a mean 33 months of follow-up.

In addition to the modification of the implant’s center of rotation suggested by these results and the numerous other experimental and clinical studies, some authors have proposed a complementary bone procedure or modification of the prosthesis design. Nyffeler et al. [22] and Kontaxis and Johnson [23] proposed an oblique osteotomy of the glenoid to prevent inferior impingement, but demonstrated the superiority of lowering the center of rotation compared to this technique. Nyffeler et al. [26] suggested modifying the implant design so as to limit the risk of impingement and notching by implanting a humeral cup with asymmetrical edges or by reducing the inclination angle of the humeral osteotomy. Some of the implants currently on the market are, therefore, designed with an inferior indentation in the cup’s polyethylene to limit inferior impingement. Yet arthroscopic analysis of the scapular notch shows that impingement is essentially postero-inferior and, therefore, the indentation of the humeral cup should be in a postero-inferior position instead of being shifted backward, to prevent impingement as much as possible.

**Conclusion**

Dynamic arthroscopic analysis of the Lima reverse shoulder prosthesis has shown the real nature of the impingement occurring between the humeral implant and the postero-inferior part of the scapular neck, the source of scapular notching. This study has also specified the seat of notching, which was inferior or postero-inferior depending on the
shoulder’s position. The positions of the shoulder that result in notching were for the most part the closest to the resting position, elbow against the body. Abduction tended to make the impingement disappear for all glenosphere diameters. External rotation increased the risk of notching and instability with 36-mm glenospheres but reduced it with 44-mm components.

The risk of instability caused by notching was reduced by increasing the prosthesis diameter but was increased by lowering the center of rotation.

To reduce the risk of scapular notching and prosthesis instability, it is therefore necessary to increase the diameter of the 36-mm glenosphere, which is the most frequently implanted, in addition to lowering the center of rotation of the reverse shoulder prosthesis. Moreover, modification of the implant design with a humeral cup including a posteroinferior indentation should, according to the observations in this arthroscopic study, also reduce the risk of impingement and scapular notching. These modifications should improve the clinical results and survival of the reverse prostheses whose indications are growing.

Disclosure of interest

The authors declare that they have no conflicts of interest concerning this article.

References