Original article

Injury to the axillary nerve after reverse shoulder arthroplasty: An anatomical study

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ABSTRACT

Background: Subclinical neurological lesions after reverse shoulder arthroplasty are frequent, mainly those involving the axillary nerve. One of the major reported risk factors is postoperative lengthening of the arm. The purpose of this study was to evaluate the anatomical relationship between the axillary nerve and prosthetic components after reverse shoulder arthroplasty. The study hypothesis was that inferior overhang of the glenosphere relative to glenoid could put this nerve at risk.

Material and methods: Eleven fresh frozen shoulder specimens were dissected after having undergone reverse shoulder arthroplasty using a classic deltopectoral approach.

Results: The mean distance from the inferior border of the glenoid to the inferior edge of the glenosphere was 6.0 ± 4.3 mm (range, 1.0 to 16.2 mm). The axillary nerve was never closer than 15 mm to the glenosphere. The main anterior branch of the axillary nerve was in close contact with the posterior metaphysis or humeral prosthetic implant. The mean distance between the nerve and the humeral implants was 5.2 ± 2.1 mm (range, 2.0 to 8.1 mm).

Conclusions: The proximity of the axillary nerve to the posterior metaphysis or humeral implants may be a risk factor for axillary nerve injury after reverse shoulder arthroplasty.

Clinical relevance: This study quantifies the proximity of the axillary nerve to the implant after reverse shoulder arthroplasty.

Level of evidence: Basic science study, cadaver study.

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1. Introduction

The Grammont designed shoulder arthroplasty reverses the ball-and-socket relationship of the shoulder. The medialization of the centre of rotation optimizes the deltoid lever arm, and by distalization of the humerus relative to the acromion, re-establishes the tension of the deltoid thus allowing this muscle to produce shoulder range of motion even in the absence of the rotator cuff. Lowering the humerus lengthens the arm, which can be increased by using a thicker polyethylene component, using a larger or eccentric glenosphere, or positioning the glenosphere on the lower part of the glenoid surface. The latter can lead to an inferior overhang of the glenosphere that may decrease the rate of scapular notching [1,2]. It has been shown that lengthening of the arm in Grammont style prostheses is necessary to obtain good postoperative function [3]. However, lengthening is also one of the major risk factors for postoperative neurological lesions [4].

Neurological lesions are frequent following reverse shoulder arthroplasty; half of these cases involve the axillary nerve, which provides innervation for the essential deltoid muscle [4]. Although most of these axillary nerve lesions do not occur as flaccid paralysis, they may be responsible for postoperative pain, weakness, dislocation, or impair rehabilitation. These lesions could theoretically occur from direct nerve damage during surgical dissection, compression secondary to retractors or postoperative hematoma, excess mobilization of the limb, vascular injury, humeral shaft...
fractures, cement extrusion, and possibly interscalenic block [5–7]. However, a previous study demonstrated that the previously mentioned factors did not seem to play a significant role [4]. The vulnerability of the axillary nerve compared to the rest of the brachial plexus could thus be due to its particular proximity to the implants or its course around the humerus. Previous studies that examined its location during other types of glenohumeral procedures did not take into account the changes induced by reverse shoulder arthroplasty [8–16]. Therefore, the position of the nerve relative to the glenosphere, humerus and implants, has not been quantified. The anatomical position of the axillary nerve could make it more specifically vulnerable to injury due to lengthening of the arm and eventually to compression in cases of secondary impingement. An appreciation of this proximity may help shoulder surgeons avoid iatrogenic injuries that can be devastating. The aim of this cadaveric study was to evaluate the anatomical relationship between the axillary nerve and the prosthetic components after reverse shoulder arthroplasty. Our hypothesis was that inferior overhang of the glenosphere would decrease the distance between reverse shoulder arthroplasty implants and the axillary nerve. This relationship may explain the high rate of axillary nerve lesions following reverse shoulder arthroplasty.

2. Materials and methods

2.1. Specimens

Eleven fresh frozen human cadaveric shoulders were dissected after thawing. The mean donor age was 89.8 years (range, 72 to 95 years). Seven of the donors were male and 4 were female. The specimens were mounted in a simulated beach-chair position, secured with a clamp on the medial scapula, and mounted onto an aluminium frame.

2.2. Surgical technique

The surgical technique was a deltopectoral approach and a subscapularis tenotomy was used to provide access to the glenohumeral joint [17]. A Delta 3 reverse shoulder arthroplasty implant was used in all cases (Delta III; DePuy, Johnson & Johnson, Leeds, UK). The size of the metaglene was 27 mm in all cases. The metaglene was implanted low on the glenoid to simulate the ideal position to avoid scapular notching. A 38 mm glenosphere was implanted in 6 cases, and a 42 mm glenosphere was implanted in 5 cases. Concentric glenospheres were implanted in 6 cases and eccentric glenospheres of 4 mm were used in 5 specimens (Table 1). The lateral landmark for the humeral cut was the top of the greater tuberosity. All the humeral stems were non-cemented and implanted high to obtain appropriate deltoid tension. The retroversion of the stem was determined according to the anatomy of the patient, but a maximum of 40° was tolerated. Non-constrained humeral liners of 6 mm were then placed on the humeral components.

2.3. Dissection

The axillary nerve anatomy has been well described [18,19]. The nerve originates from the posterior cord of the brachial plexus, runs anteriorly towards the subscapularis muscle and posterior to the axillary artery, passing under the inferior capsule between the glenoid rim and the humeral metaphysis, supplying a branch to the shoulder joint, and crosses the quadrilateral space. At this point, the nerve splits into a main anterior circumflex division, which innervates the deltoid muscle and provides a few cutaneous filaments. A posterior division gives the superior-lateral brachial cutaneous nerve and the nerve to the teres minor [20]. The anterior division runs deep towards the deltoid and winds around the surgical neck of the humerus, between five to seven centimetres from the lateral border of the acromion [18]. The posterior division takes a postero-medial course along the origin of the lateral head of the triceps, below the rim of the glenoid cavity, sometimes bearing an enlargement (“pseudo-ganglion”).

Dissection of the axillary nerve was performed following implantation of the reverse components using a classical deltopectoral approach. The subscapularis tendon had been anatomically repaired to avoid modification of the position of the axillary nerve. The previous deltopectoral incision was enlarged. The upper humeral insertion of the pectoralis major was cut and retracted medially. Tenotomy of the conjoint tendon was performed to provide a better access for the exploration of the brachial plexus.

The distance between the inferior borders of the glenoid and the inferior glenosphere was measured. The axillary nerve was then dissected and the shortest distance to the glenosphere was measured. Posterior exposure was then obtained through a vertically oriented incision over the posterior aspect of the shoulder joint. The posterior part of the deltoid was retracted laterally and superiorly allowing exposure of the quadrilateral space. The posterior part of the rotator cuff was not removed. The main anterior circumflex branch of the axillary nerve was then dissected and isolated (Fig. 1). The distance between the nerve and prosthetic components, including polyethylene, were recorded. If the posterior capsule was not damaged, a dissection was performed to allow measurement. All measurements were performed with a manual calliper (Etalong, Roch, Switzerland). Each measurement was performed three times by two separate examiners, and the final results were calculated as the average value between them. If a measurement was above 15 mm, no further dissection was performed in an attempt to preserve soft tissue and landmarks.

2.4. Statistical analysis

The descriptive analysis consisted of frequencies and percent-ages for discrete data. Means and standard deviations were used

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**Table 1**

Results of measures.

<table>
<thead>
<tr>
<th>Cadaver No</th>
<th>Side</th>
<th>Age (year)</th>
<th>Sex</th>
<th>Glenosphere size (mm)</th>
<th>Eccentric glenosphere (mm)</th>
<th>Distance from the inferior glenoid to inferior glenosphere (mm)</th>
<th>Distance from axillary nerve-glenosphere (mm)</th>
<th>Distance from axillary nerve to humeral component (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Right</td>
<td>89</td>
<td>F</td>
<td>38</td>
<td>0</td>
<td>2.0</td>
<td>&gt;15</td>
<td>8.1</td>
</tr>
<tr>
<td>2</td>
<td>Left</td>
<td>91</td>
<td>M</td>
<td>42</td>
<td>4</td>
<td>7.4</td>
<td>&gt;15</td>
<td>7.2</td>
</tr>
<tr>
<td>3</td>
<td>Right</td>
<td>92</td>
<td>M</td>
<td>38</td>
<td>0</td>
<td>4.0</td>
<td>&gt;15</td>
<td>5.7</td>
</tr>
<tr>
<td>4</td>
<td>Left</td>
<td>92</td>
<td>M</td>
<td>38</td>
<td>0</td>
<td>2.0</td>
<td>&gt;15</td>
<td>6.4</td>
</tr>
<tr>
<td>5</td>
<td>Left</td>
<td>85</td>
<td>M</td>
<td>42</td>
<td>4</td>
<td>16.2</td>
<td>&gt;15</td>
<td>6.3</td>
</tr>
<tr>
<td>6</td>
<td>Right</td>
<td>91</td>
<td>M</td>
<td>42</td>
<td>4</td>
<td>6.2</td>
<td>&gt;15</td>
<td>3.2</td>
</tr>
<tr>
<td>Mean (SD)</td>
<td></td>
<td>90.0 (2.7)</td>
<td></td>
<td></td>
<td></td>
<td>5.7 (4.0)</td>
<td>&gt;15</td>
<td>6.2 (1.7)</td>
</tr>
</tbody>
</table>

F: female; M: male; SD: standard deviation.
branches to muscles, capsule, and skin [20]. The susceptibility of this nerve to sustain direct or traction injury during surgical procedures has been well documented [10,22,25–28]. A recent electrodiagnostic study documented an alarmingly high prevalence of neurological lesions after reverse shoulder arthroplasty [4]. Nine of 19 shoulders (45%) developed an acute postoperative axillary nerve lesion or postoperative worsening of pre-existing asymptomatic neurologic abnormalities. However, no explanation was found for the higher prevalence of neurological lesion of the axillary nerve compared to the remainder of the brachial plexus. Furthermore, no relationship was demonstrated between an inferior overlap of the glenosphere greater than or equal to 5 mm and the development of neurological impairment (P = 1.000) [29]. Another study estimated the strain on infracavicular branches of the brachial plexus using a three-dimensional reconstruction technique coupled with computed tomography, comparing nerve length both before and after reverse shoulder arthroplasty. Interestingly, they found strain in all branches of the plexus except for the axillary nerve that was unexpectedly shortened. However, a single cadaver was used for this study and therefore, no general conclusions can be drawn from those results [30]. The present study shows that the axillary nerve is not in close proximity to the glenosphere after implantation of a reverse shoulder arthroplasty. The distance between the nerve and the glenosphere was systematically greater than 15 mm. As this distance is larger than the normal anatomic position relative to the glenoid, the hypothesis of the current study is not supported; inferior glenosphere overlap does not appear to decrease the distance to the axillary nerve. Rather, it seems that the lengthening of the arm after a reverse shoulder arthroplasty leads to a lowering and lateralization of the nerve and protects it from impingement with the glenosphere component. Therefore, the position of the glenosphere in the vertical plane is probably not related to the development of a neurological lesion due to direct contact.

Another factor contributing to the development of an axillary nerve lesion after lengthening of the arm could be the course of the main anterior circumflex branch of the axillary nerve which is relatively fixed around the humeral metaphysis. Contact between the main anterior circumflex branch and the humeral metaphysis was obvious in 3 out of 6 specimens (33%) (Fig. 1). Caution should therefore be observed when reaming the metaphysis to avoid posterior humeral cortical violation, particularly when having a low humeral cut and using a large reamer. To prevent such lesions, the use of a combination of polyethylene adaptor systems that allow the use of a large glenosphere with a small metaphysis, might be an option. Another way to prevent excessive cortical reaming is to respect the natural version of the humerus and not to choose a fixed figure of retroversion (i.e. 20 or 30°); if the natural angle is smaller. Lateral offset of glenosphere from the glenoid surface may be another possibility since this approach provides sufficient stability without excessive lengthening. This approach may also theoretically relieve tension to the axillary nerve in the quadrilateral space. Further studies are needed to examine this relationship.

Despite the proximity of the nerve to the prosthesis and the humeral metaphysis, there are few case reports in the literature of clinically evident (as oppose to electro-diagnostically apparent) postoperative axillary nerve injury [43,41–43]. This can be explained by the fact that transient partial lesions (neuapraxia) of the main anterior circumflex branch of the axillary nerve, which leads to weakness of the deltoid muscle, can remain unnoticed in the postoperative period. Additionally, more severe lesions such as axonotmesis can be compensated for either by other motor branches in a process of intramuscular collateral re-innervation, or by muscle hypertrophy [34].

To our knowledge, this is the first study to describe the proximity of the axillary nerve to the implant after reverse shoulder arthroplasty. However, the present study has some limitations. First, the

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3. Results

The results are summarized in Table 1. The mean distance from the inferior border of the glenoid to the inferior glenosphere was 6.0 ± 4.3 mm (range, 1.0 to 16.2 mm). There was no proximity between the main anterior circumflex branch of the axillary nerve and the glenosphere (>15 mm in all cases). The main anterior circumflex branch of the axillary nerve was in close contact to the humeral metaphysis with a mean distance of 5.2 ± 2.1 mm (range, 2.0 to 8.1 mm) between the nerve and the metaphysis. Contact between the main anterior circumflex branch and the humeral implant was obvious in 3 out of 6 specimens (case 3 and 6). The only structure separating the nerve from the humeral implants was the thin capsule, when present. The capsule was damage by the metaphyseal reaming in 1 case.

4. Discussion

The causes of nerve injury after reverse shoulder arthroplasty are multifactorial and include direct nerve damage during surgical dissection, compression secondary to retractors or postoperative hematoma, excessive mobilization of the limb, vascular injury, humeral shaft fractures, cement extrusion, and possibly interscalenic nerve block [5–7]. The purpose of this study was to characterize the location of the axillary with regard to reverse shoulder arthroplasty in order to obtain information that may be useful in preventing axillary nerve injury during this procedure.

The axillary nerve can be in close proximity to the glenoid rim, and thus to prosthetic components used in reverse shoulder arthroplasty. Previous studies have demonstrated that the mean distance between the axillary nerve and the glenoid rim is between 3.2 mm and 12.4 mm [13,21–24]. The nerve then exits posteriorly through the lateral axillary space and gives the anterior and posterior

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![Fig. 1. Posterior view of right shoulder showing in detail the lateral axillary space after implantation of a reverse shoulder arthroplasty. The main anterior circumflex branch of the axillary nerve courses distally around the metaphysis and is in close contact with the humeral trial liners. (AN [black arrows]: main anterior circumflex branch of the axillary nerve; *: blue humeral liners; D: deltoid muscle; TB: long head of the triceps brachii muscle; TM: teres minor).](image-url)
sample size was small. Even if the method of implantation was standardized, the potential variability in implants positioning, such as amount of version, represents a wide number of clinical situations. Secondly, this anatomical cadaveric study does not take into account different shoulder positions or muscular contraction. We have observed a few patients who develop neurological symptoms when their abduction brace is removed at 4 weeks postoperatively. Such phenomena could be explained by a dynamic compression of the nerve by soft tissue when the arm is adducted. Third, the cadavers used were of an elderly population. Muscle and soft tissue might be thicker in younger people, which could possibly make the distances measured in this study shorter. However, the implantation of a reverse prosthesis should usually not be considered before the age of 70. These factors may consequently be irrelevant and do not likely play a significant role in this study. Fourth, the cadaver specimens were only of the shoulder girdle. As the specimens do not include the full upper thorax and neck, they may not have the appropriate stretch on the brachial plexus and this may alter the position of the normal anatomic position of the nerves. Finally, the lateral and superior retraction of the deltoid required to access the shoulder and obtain measurements (Fig. 1) could change the position of the axillary nerve and bring it closer to the prosthesis.

Conclusions

The proximity of the axillary nerve to the posterior metaphysis or humeral implants may be a risk factor for neurological lesions after reverse shoulder arthroplasty.

Disclosure of interest

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

References