ORIGINAL ARTICLE

Geometrical analysis results of 42 resurfacing shoulder prostheses: A CT scan study

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KEYWORDS
Shoulder; Prosthesis; Computed tomography scanner

Summary
Background: Shoulder resurfacing arthroplasty was introduced in Scandinavia in the early 1980s then developed by SA Copeland.
Hypothesis: Resurfacing prostheses restore the normal anatomy of the proximal humerus. Here, our objective was to evaluate humeral resurfacing prosthesis position on radiographs and computed tomography (CT) images.
Materials and methods: We retrospectively reviewed 42 consecutive cases seen at a single centre between 2004 and 2009. Mean patient age was 65 years. CT was performed routinely before prosthesis implantation and at re-evaluation. The Copeland Mark III® (Biomet France SARL, 26903 Valence, France) implant was used in 32 cases and the Aequalis Resurfacing Head® (Tornier France, 38334 Saint-Ismier, France) in 10 cases. The post-implantation CT images were used to measure the angle of inclination, medial humeral offset, lateral glenohumeral offset, and version of the implant.
Results: Mean follow-up was 18 months. Compared to baseline, no significant changes were found at re-evaluation for the angle of inclination or lateral glenohumeral offset. In contrast, medial humeral offset increased by 3.47 mm, and excessive anteversion of 4.23° compared to the bicondylar line was noted.
Discussion: Humeral head resurfacing prostheses restore the overall anatomy of the proximal humeral head. Our CT scan evaluation protocol seems reproducible and enables an evaluation of implant geometry. In our experience, resurfacing arthroplasty restored the native humeral offset. Inadequate retroversion was noted and was probably related to insufficient exposure during surgery.
Level of evidence: Level IV, retrospective study.
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Introduction

Shoulder resurfacing arthroplasty (SRA) has the theoretical advantages of respecting humeral head anatomy and preserving humeral bone stock, which would be expected to promote favourable glenohumeral kinetics and optimal periaricular muscle function. The simplicity of the implant and ancillary instruments might seem to suggest an easy and reproducible technique. However, during implantation, challenges may arise when attempting to ensure optimal implant position (varus or valgus, implant version, or lateral offset). SRA was introduced in Scandinavia in the early 1980s [1] but was subsequently developed by S. Copeland [2–9] and evaluated in clinical studies of patients with a variety of shoulder disorders.

The Mark I® implant was made of titanium and had a central, smooth, perforated peg that was secured with a screw inserted through the lateral aspect of the proximal humerus to exert compression and prevent rotation, as no cement was used. This design was associated with loosening and migration and was therefore discarded in the early 1990s. Mark II® was a cobalt-chromium prosthesis that had a central, cone-shaped, grooved, press-fit post. The next improvement consisted in adding a hydroxyapatite coat to the concave surface of the implant to improve stability and promote bone integration (Mark III®). The various implant dimensions were selected based on radiographic studies of normal and osteoarthritic cadaver shoulders and followed anatomic rules as opposed to mathematical rules [6, 10]. At present, many resurfacing prosthesis models are available. They were developed in part based on anatomic prosthesi design using the criteria developed by Pearl and Kurutz [11–14].

In the orthopaedics A department (Prof. Mestdagh and Prof. Maynou) of the Lille Teaching Hospital, Lille, France, SRA has been used since 2004. The objective of this study was to determine whether SRA restored the native proximal humeral anatomy, as assessed using computed tomography (CT) measurements.

Material and methods

Patients

We retrospectively reviewed the charts of 47 consecutive patients (including three with bilateral arthroplasty) who underwent SRA at a single centre between 2004 and 2009. Seven different surgeons performed the procedures. There were no exclusion criteria. All patients were to be re-evaluated by an independent assessor.

A clinical re-evaluation was performed in 39 patients; one patient was lost to follow-up and seven either were too ill or lived too far away to travel to our centre. Of these 39 patients, three underwent bilateral SRA: thus, the study included 42 shoulders. There were 25 women and 14 men with a mean age of 65 years (range, 45–83 years) at surgery. The dominant side was affected in 24 cases and the non-dominant side in 18 cases.

A history of surgery was noted for only two shoulders. Open repair of the rotator cuff tendon had been performed 3 years earlier in a woman whose CT scan performed before SRA showed an intact cuff. In a male patient, a comminuted extra-articular fracture of the proximal third of the humerus 30 years earlier had been treated with screw-plate fixation and autologous bone grafting.

Operative technique

Templates and radiographs of appropriate scale were routinely used to plan the procedure.

The patient was in the beach-chair position. The deltopectoral approach was used in all cases. The subscapularis tendon was divided 1 cm from its implantation on the lesser tuberosity. The long head of the biceps brachii muscle was divided in 38 (90.5%) cases; in the remaining four cases, tenodesis in the bicipital groove was performed. Peripheral osteotomies were removed routinely to allow accurate definition of the neck of the humerus. The anterior humeral circumflex vessels were exposed and preserved. The drill guide was positioned using the positioning phantom without fluoroscopy. The angle of inclination of the prosthesis was assessed relative to the anatomic neck and implantation site of the deep supraspinatus tendon fibres. Implant version was evaluated relative to the axis of the forearm.

No procedures were performed on the glenoid cavity. A single patient required a complementary procedure, which consisted in repair of an isolated distal tear of the supraspinatus tendon, without tendon retraction.

The underlying aetiologies were distributed as follows:

- primary glenohumeral osteoarthritis (GHOA) in 33 (78.6%) cases, including 16 stage 4, 13 stage 3, and four stage 2 in the modified Samison and Prieto classification [15];
- avascular necrosis (AVN) in the absence of trauma in four (9.5%) cases, including three stage 3 and one stage 4 in the Arlet and Ficat classification as modified by Crues [16];
- cuff tear arthropathy (CTA) complicating massive cuff tears in four (9.5%) cases, all of which were stage V in the Hamada classification scheme [17], with alterations in glenoid cavity bone stock that precluded implantation of a glenoid component;
- rheumatoid arthritis (RA) in 1 case.

A Mark III® implant was used in 32 cases and an Aequalis Resurfacing Head® implant in 10 cases. The Mark III® implant was made of a chromium-cobalt alloy with a coat of hydroxyapatite over the concave surface and was intended for implantation without cement. Five sizes were available. The radius of curvature of the implants used was 50 mm. As implant size was determined based on anatomic factors, as opposed to a mathematical rule, variable diameter differences occurred from one size to the next. The Aequalis Resurfacing Head® was also made of a chromium-cobalt alloy and intended for cementless implantation. Twelve sizes were available, with cap diameters ranging from 37 to 54 mm and two available heights for the three largest diameters. Peg length was 30, 35, or 40 mm depending on cap size. Cap dimensions were identical to those of Aequalis humeral heads for hemiarthroplasty. Mean difference in diameter from one size to the next was 2 mm. Primary fixation was ensured by a cone-shaped tri-fin peg and a diamond-shaped...
The macrotexture of the concave surface with an overlying coat of hydroxyapatite.

**Implant geometry assessment methods**

Before and after SRA, three anteroposterior radiographs were obtained, in neutral, external, and internal rotation, respectively, as well as a scapular Y-view. Postoperative radiographs were examined for the following:

- a lucent line around the implant, classified depending on thickness (<1 mm, 1–2 mm, and >2 mm) and location;
- subchondral sclerosis or geodes on the glenoid side of the joint;
- implant migration;
- and, on the anteroposterior view in neutral rotation, the angle of inclination of the implant relative to the axis of the diaphysis, measured as the angle formed by the line through the implant peg (line P) and the diaphyseal axis (line D) (Fig. 1).

CT-arthrography was performed preoperatively in 38 (90.5%) patients. The remaining four patients underwent both preoperative CT without contrast injection and ultrasound. Findings from these imaging studies included rotator cuff tears [18] in eight (19%) cases, with two isolated supraspinatus tears (distal Type 1 without fatty infiltration [19]), two tears involving both the supraspinatus and the infraspinatus (intermediate Type 2 tears with fatty infiltration grade 2 and 4, respectively), and four massive tears of the supraspinatus, infraspinatus, and subscapularis (Type 3 retraction with grade 4 fatty infiltration).

Glenoid morphology was evaluated in the horizontal plane according to Badet et al. [20] and in the coronal plane according to Favard et al. [21,22], on both the preoperative and the postoperative images.

The preoperative CT images were used to evaluate the parameters listed below:

- cervicodiaphyseal angle or angle of inclination of the humeral head relative to the diaphysis. We selected the CT section on which visibility of the diaphyseal axis (line D) was optimal then the CT section on which the anatomic neck was best defined. We traced a line (line A) perpendicular to, and through the middle of, the anatomic neck. Using digitised images and the copy-paste function, we artificially superimposed the two lines to obtain an accurate measurement of the cervicodiaphyseal angle (Fig. 2);
- medial humeral offset, or distance between the centre C of the humeral head and the diaphyseal axis. Using the CT section on which the entire humeral head was visible, we identified point C by tracing a circle following the humeral head contours on the computer. The diaphyseal axis (line D) was traced on the section on which it was visible most clearly, and the line through C and perpendicular to line D was traced. We then used the computer to superimpose these two lines. The distance between C and line D along the perpendicular line accurately reflected the medial humeral offset (Fig. 3);
- lateral glenohumeral offset defined as the distance between the most lateral edge of the coracoid process (line C) and the most lateral edge of the greater tuberosity (line T) on axial CT sections. Line C was traced on the section on which the lateral part of the coracoid process was most clearly visible (Fig. 4) and line T on the section where the greater tuberosity was most clearly visible. Line T was the line running perpendicular to the section plane and through the most lateral edge of the greater tuberosity. As with the previous two measurements, we superimposed the two lines (here, C and T) on the same image, traced the line perpendicular to lines C and T, and

![Figure 1](image1.png)  **Figure 1**  Measurement of implant inclination on the anteroposterior radiograph in neutral rotation as the angle between line P through the implant peg and line D along the diaphyseal axis.

![Figure 2](image2.png)  **Figure 2**  Measurement of the cervicodiaphyseal angle as the angle between line D along the diaphyseal axis and line A along the axis of the humeral head.
measured the distance separating lines C and T, which was equal to the lateral glenohumeral offset (Fig. 5);
• humeral head version relative to the biepicondylar line could not be measured preoperatively, given the marked heterogeneity of the CT scans, some of which were performed in office practices.

CT was routinely performed after SRA, using a strict protocol:

• no contrast agent injection;
• visualisation of the entire glenohumeral and acromioclavicular joints and field extending to the deltoid V;
• use of bony windows and soft tissue windows;
• 0.5-mm slices;
• arm in neutral rotation;
• and acquisition of images of the distal humerus on the operated side for calculation of implant retroversion.

The CT evaluation included an assessment of glenoid cavity geometry in the coronal and horizontal planes, detection of prosthesis loosening, and evaluation of bone behaviour within the implant. The angle of inclination of the implant (Fig. 6), medial offset (Fig. 7), and lateral offset (Fig. 8) were measured as described above for the
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Statistical analysis

Quantitative variables were compared using Student’s t test for paired samples and qualitative variables using Fisher’s test. The Wilcoxon test was used to compare continuous variables. Values of p smaller than 0.05 were considered significant.

We used the Fleiss method to evaluate the reproducibility of the postoperative measurements, which were performed by two observers working independently of each other (one senior surgeon and one senior radiologist). The four CT scan measurements were reproducible, with R-values of 0.98 for inclination, 0.98 for medial humeral offset, 0.94 for lateral glenohumeral offset, and 0.99 for version. Therefore, for the remainder of the study we used the mean of the values obtained by the two observers.

Results

Radiographic and CT findings

Mean follow-up was 18 months (range, 2.6–57 months).

The radiographs obtained at re-evaluation showed no periprosthetic lines or evidence of implant migration. The comparison of radiographs obtained preoperatively and at last follow-up showed no osteolysis or macrogeodes in the glenoid cavity. Mean implant inclination on anteroposterior radiographs in neutral rotation was 131.52° (range, 98°–156°).

In a patient who reported persistent pain at last follow-up, CT at re-evaluation disclosed microgeodes in the glenoid cavity that were not visible on the standard radiographs. The implant backing generated an abundance of noise that precluded an evaluation of bone structure under the implant. According to the Badet et al. classification scheme [20], glenoid cavity morphology before SRA was A1 in 22 (52.4%) cases, A2 in 14 (33.3%) cases, B1 in four (9.5%) cases, and B2 in two (4.8%) cases. After SRA, glenoid cavity morphology was A1 in 19 (45.2%) cases, A2 in 20 (47.6%) cases, and B1 in three (7.2%) cases. Three of the A1, one of the B1, and both B2 glenoid cavities were A2 at re-evaluation. Preoperatively, glenoid cavity wear in the coronal plane according to the Favard et al. classification scheme [21,22] was E0 in 20 (47.6%) cases and E1 in 22 (52.4%) cases. At re-evaluation, wear was E0 in 15 (35.7%) cases and E1 in 27 (64.3%) cases (five of the initially E0 glenoid cavities were E1 at re-evaluation).
Mean humeral head inclination before SRA as measured on CT images was 129.79° (range, 110°–142°). Mean implant inclination at re-evaluation was 129.09° (range, 106.85°–142.5°). The difference between the preoperative and postoperative angles of inclination was not statistically significant (Table 1).

Mean medial humeral offset was increased significantly, from 4.05 mm (range, 1–10 mm) before SRA to 7.52 mm (range, 2.1–14.45 mm) at re-evaluation (P < 0.0001). The increase was 3.47 mm (range, −2.9 to +13.45 mm).

Mean lateral glenohumeral offset was 49.08 mm (range, 30–63 mm) before SRA and 49.28 mm (range, 33.2–66.25 mm) at re-evaluation. The difference was not statistically significant.

Mean implant version relative to the biepicondylar line was 4.23° (range, −35° to +36°). The statistical analysis showed no significant correlation between implant version and the other CT measurements obtained for this study.

Table 1: Computed tomography measurements obtained in our study.

<table>
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<th>Preoperatively</th>
<th>Last follow-up</th>
<th>Difference</th>
<th>P value</th>
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<td>Inclination</td>
<td>129.79°</td>
<td>129.09°</td>
<td>−0.70 mm</td>
<td>0.5406NS</td>
</tr>
<tr>
<td>Medial humeral offset</td>
<td>4.05 mm</td>
<td>7.52 mm</td>
<td>+3.47 mm</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Lateral gleno-humeral offset</td>
<td>49.08 mm</td>
<td>49.28 mm</td>
<td>+0.20 mm</td>
<td>0.8505NS</td>
</tr>
<tr>
<td>Version</td>
<td>Unknown</td>
<td>4.23°</td>
<td></td>
<td></td>
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</table>

Discussion

In our experience, implants designed for humeral head resurfacing respected the native angle of inclination and lateral glenohumeral offset and restored the native medial humeral offset.

A theoretical advantage of shoulder resurfacing implants is preservation of proximal humeral anatomy, which is known to vary widely across individuals. The result is good-quality glenohumeral kinetics via preservation of the force couples of the periaricular muscles. Additional potential advantages of resurfacing implants include expected simplicity of the surgical procedure, bone stock preservation, ease of revision surgery if needed, and absence of cementing. SRA usually consists in a hemiarthroplasty, as preservation of the humeral head complicates access to the glenoid cavity.

The objective of our study was to evaluate resurfacing implant position via geometric measurements performed on CT images. To our knowledge, this is the first CT study designed to investigate whether resurfacing implants allow preservation of the native anatomy.

Biological resurfacing of the glenoid cavity has been evaluated by a few authors, with conflicting results. Although Krishnan et al. [23] advocated the use of an allogeneic calcaneal tendon graft, many studies [24–26] showed increased glenoid cavity wear regardless of the type of graft (allogeneic lateral meniscus, autologous fascia lata, or interposition of the anterior joint capsule). In our study, none of the patients underwent biological glenoid cavity resurfacing, as this procedure has not been proven effective and creates considerable technical challenges given the limited surgical access.

The radiographic behaviour of resurfacing implants coated with hydroxyapatite seems satisfactory. Levy and Copeland [7, 8] found no radiological lines or evidence of loosening around Mark III® implants, in keeping with reports by Mullet et al. [9] and Raiss et al. [27]. In a case-series of 56 Mark III® SRAs, Thomas et al. [10] detected radiolucent lines beneath three implants, including one with loosening. In keeping with earlier data, the absence of radiolucent lines after 18 months of follow-up in our study suggested good bone integration of the implant. The artefacts generated by the shape and cobalt-chromium alloy composition of the implant precluded an evaluation of bone tissue behaviour under the cap. An optimised imaging protocol involving adjustments of the filters and slice thicknesses might improve bone tissue visualisation under the cap.

CT evaluation of glenoid cavity wear showed a slight increase in A2 cavities (from 33.3 to 47.6%) and disappearance of the two B2 cavities. In the coronal plane, the proportion of E1 glenoid cavities increased from 52.4 to 64.3%. These results reflect concentric wear of the glenoid cavity to adapt to the humeral cap.

In a study of 39 SRAs with a follow-up of 38 months, Thomas et al. [28] found a 5-mm increase in medial humeral offset. Lateral humeral offset was increased by 6 mm on the postoperative radiographs and 4 mm at last follow-up. However, there was evidence of systematic measurement error related to difficulties in locating the base of the coracoid process used as a fixed landmark. Humeral offset failed to correlate with clinical outcomes. In the radiographic study by Coutié and Mansat [29], 31 SRAs were re-evaluated after 22 months. Humeral offset increased by 1.9 mm and the angle of inclination of the head decreased from 127° to 119°. The lateral view was insufficiently reproducible to allow an evaluation of implant version. Ohl et al. [30] studied 19 hemiarthroplasties with follow-ups longer than 2 years, including 13 SRAs. On standard radiographs, lateral glenohumeral offset was measured as the distance between the lateral edge of the greater tuberosity and the base of the coracoid process. In the overall population, lateral gleno-humeral offset showed a mean increase of 2.7 mm between the preoperative and immediate postoperative radiographs. Unfortunately, this parameter was not available at last follow-up.

Our CT study results are consistent with those of earlier radiographic studies. Advantages of our CT method include the excellent interobserver reproducibility and ability to...
measure implant version. The main limitation of our study is the absence of measurement of humeral head version before SRA.

We found no significant differences between the preoperative and postoperative values of implant inclination and lateral humeral offset. Implant inclination in the coronal plane was 129.79° preoperatively and 129.09° postoperatively (in agreement with the mean inclination of 131.52° on standard radiographs). Lateral glenohumeral offset was 49.08 mm preoperatively and 49.28 mm postoperatively, indicating perfect preservation of humeral head inclination and of the lever arm of the periarticular muscles, which guarantee satisfactory glenohumeral kinetics.

After SRA, we found anteverision of the implant, with a mean of 4.23°. This value cannot be compared to the preoperative version of the head, as the preoperative CT protocol did not include sections through the bicipital tuberosity. Although cephalic version shows considerable interindividual variability [31,32], the anteverision noted in our study is probably ascribable to a technical deficiency related to inadequate surgical exposure. The deliberate minimisation of the surgical incision and preservation of the anterior circumflex pedicle may explain the limited exposure and absence of implant retroversion.

Mean medial humeral offset increased by 3.47 mm. One possible explanation is inadequate reaming of the humeral head. Another is restoration of the native medial offset previously decreased due to wear of the humeral head cartilage. Finally, the increase in medial humeral offset may be related to a cap that is too large or inadequately impacted, although the absence on radiographs and CT scans of linear luencies or loosening argues against this possibility.

Several factors may explain the discrepancy between the stability of the lateral glenohumeral offset and the increase in the medial humeral offset. Glenoid cavity wear can result in stabilisation of lateral glenohumeral offset despite an increase in medial humeral offset. Follow-up in our study was too short to assess this possibility, although most of the glenoid cavities showed concentric wear (A2) at last follow-up. A longer-term study would be needed to evaluate this hypothesis. Another possibility involves the position of the greater tuberosity during CT image acquisition. This position may be affected by the position of the arm (most notably before SRA) or by the excessive version of the implants in our study, with a decrease in lateral glenohumeral offset as a result.

In conclusion, our CT evaluation protocol seems reproducible and allows an accurate assessment of the main geometric characteristics of shoulder resurfacing implants. In our experience, SRA respected the native anatomy in terms of inclination and lateral glenohumeral offset and restored the native medial humeral offset. The inadequate retroversion in our study is probably ascribable to insufficient exposure during surgery.

Disclosure of interest

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

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