The purpose of this retrospective study was to assess the effect of the reduced medialisation of the Arrow\textsuperscript{*} reverse shoulder prosthesis on short-term clinical and radiological results. The clinical and radiological results of 47 Delta III\textsuperscript{*} reverse prostheses and 49 Arrow\textsuperscript{*} reverse prostheses were retrospectively compared at a minimum of twelve months follow-up. There was a significant increase ($p<1.10^{-4}$) in range of motion from the preoperative range in the two groups except for internal rotation in the Delta III group ($p=0.1$). Radiological analysis on antero-posterior view in neutral position showed greater lateralisation ($p<0.001$) with the Arrow prosthesis. Scapular notching was noted in 32 patients with a Delta III prosthesis, and in no instance with an Arrow prosthesis. Complication rates were 14.9\% for the Delta group and 10.2\% for the Arrow group.

The design features of the Arrow prosthesis – reduced medialisation of the center of rotation with lateralisation of the humerus – were found to be associated with slight improvement in range of motion and absence of scapular notching.

**Keywords**: reverse shoulder arthroplasty; scapular notching.

**INTRODUCTION**

Reverse shoulder arthroplasty can yield satisfactory results in patients with pseudoparalysis of the shoulder due to glenohumeral osteoarthritis associated with an irreparable rotator cuff tear (5,25,26,28,30). Medialising and lowering the center of rotation improves the lever arm of the deltoid, particularly when the rotator cuff is deficient. This design of reverse prostheses decreases shearing forces at the glenoid component bone interface, and results in improved survival rate of the glenoid component compared with other constrained and semiconstrained designs (5,26,28,30). However medialisation of the center of rotation and of the humerus stem encourages impingement of the humeral polyethylene insert on the scapular neck, resulting in inferior scapular notching. The high rates of scapular notching reported (28,30) adversely affect the mid-term clinical outcome (27) and represent a potential risk of glenoid loosening on the long term (9).

As reported by Nyfeller et al (23) mechanical failure of the baseplate has been associated with polyethylene wear, chronic inflammation of the
joint capsule and local osteolysis. Although good short- and mid-term clinical results were observed with the Delta III reverse prosthesis (DePuy, Warsaw, USA), scapular notching has been a frequent complication (28-30). Frankle et al (11) proposed a more lateralised center of rotation to avoid scapular notching, with better rotations compared to the results of Sirveaux et al (28) but with a high rate of complications (17%). Excessive lateralization of the center of rotation results in increased torque and shear forces at the glenoid component-bone interface, as previously reported for constrained and semi-constrained designs (5,26,28,30). Improvement in the fixation of the baseplate in semi-constrained prostheses can allow for a moderate lateralisation of the center of rotation. In the Arrow reverse prosthesis (FH Orthopedics, France), the convex design of the baseplate backside, combined with press fit fixation (central keel and anterior extension) allows lateralisation of the center of rotation with a good primary fixation.

The purpose of this study was to compare the clinical and radiological results of the more lateralized Arrow reverse shoulder prosthesis with those of the Delta III reverse prosthesis.

**MATERIALS AND METHODS**

**Patient Selection**

The study included all patients who received a Delta III reverse shoulder prosthesis (36 mm) or an Arrow reverse shoulder prosthesis implanted by one of the senior authors and who had a minimum follow-up of 12 months. All patients included in this study were treated for irreparable rotator cuff tears with pseudoparalysis of the shoulder defined as the inability to actively elevate the arm > 90° in the presence of free passive anterior elevation. The patients did not display a hornblower’s sign preoperatively. Gerber’s test was not performed in all patients.

Patients with rheumatoid arthritis, revision surgery (failed hemi or total arthroplasties) and post-traumatic osteoarthritis were not included.

The first group included patients operated with the Delta III prosthesis between December 1993 and March 2003. There were 51 patients with 51 prostheses implanted. Follow-up was available for 47 patients. The mean age was 73.3 years (58-88); there were 36 women and 11 men. Eight shoulders had undergone previous surgery: four had a prior cuff repair; two had a deltoid flap and two had a tenodesis of the long head of the biceps. The mean follow-up for this group was 42.8 months (min 12, max 120, SD 22.2).

The second group included 50 patients with 50 Arrow prostheses implanted by the same surgeons between April 2003 and January 2006. Follow-up was available for 49 patients. The mean age was 74.9 years (52-89); there were 38 women and 11 men. Nine shoulders had undergone previous surgeries: cuff repair in four, tenotomy of the long head of the biceps in three, acromioplasty and deltoid flap in one each. The mean follow-up for this group was 19.1 months (min 12, max 40, SD 7.3).

**Surgical technique**

We mostly used the superolateral approach with an anterior deltoid split (in 44 cases in the first group, in 41 cases in the second group). In stiff shoulders, when the approach to the joint was expected to be difficult, we used a deltopectoral approach (3 cases in the first group, 8 cases in the second group). Supra- and infraspinatus tendons were irreparable in all cases, with retraction to the level of the glenohumeral joint or thin with an atrophic muscle and advanced fatty infiltration.

Differences in surgical technique between the two groups were related with the designs of the glenoid and humeral components of the two prostheses. With the Delta III prosthesis, implantation of the humeral stem requires a large metaphyseal bone resection, and the proximal part of subscapularis is frequently detached. The metaphyseal reamers remove all the cancellous bone, and cement fixation of the stem is recommended. The back surface of the baseplate is flat and comes in one size only. The quality of the fixation depends on the diverging positions of the screws into the coracoid and the pillar of the scapula. With the Arrow prosthesis, the shape of the humeral stem is similar to the anatomical prosthesis; the metaphyseal bone resection preserves enough metaphyseal cancellous bone to obtain good press fit fixation, so that cement was used in the diaphysis only in osteoporotic bone. The back side of the baseplate is convex, with three sizes to achieve optimal glenoid adaptation.

**Postoperative rehabilitation**

All patients were managed with a simple sling postoperatively, with the arm at the side and the shoulder in...
internal rotation; the sling was worn for four weeks to allow healing of the anterior deltoid, and passive range-of-motion exercises were started the day after surgery. Active assisted activities and active range of motion were initiated after four weeks.

Assessment

Clinical evaluation was performed in all patients before operation and at last follow-up, using the 100-point rating system of Constant and Murley (7) (pain on a scale of 15 points, activity of daily living: 20 points and strength: 25 points). Ranges of active and passive movement were assessed visually for forward elevation and abduction, external rotation with the arm at the side (ER1), external rotation at 90° of abduction (ER2) and for internal rotation. The mean follow-up was 42.8 months (min 12, max 120, SD 22.2) for the first group with the Delta Prosthesis and 19.1 months (min 12, max 40, SD 7.3) for the second group with the Arrow prosthesis.

Radiological evaluation at one year follow-up included a true anteroposterior view of the glenohumeral joint in neutral rotation, made under fluoroscopic control. We looked for signs of glenoid component loosening (radiolucent lines around the base plate, hardware breakage, change in base plate position) and for the presence of scapular notching, using the classification of Nerot (fig 1) with five grades according to the size of the defect as seen on the radiograph (29).

Positioning of the prosthesis was also evaluated on this film by measuring distances between the center of rotation and the greater tuberosity (lateral offset), between the acromion and the greater tuberosity, and between the acromion and the humerus (fig 2). The radiologic measurements are limited by the difficulties to reproduce the same positioning of the arm in neutral position. Radiographs were obtained under fluoroscopic control to minimise the influence of the position of the shoulder during x-ray exposure.

All measurements were made by the same surgeon. The center of rotation of the Delta prosthesis is at the level of the glenoid bone because the glenosphere covers the baseplate. In the Arrow prosthesis, the increased thickness of the baseplate and the apposition of the glenosphere result in 3.5 mm lateralisation of the center of rotation.

Statistical analysis

Univariate linear models were fitted to assess the effect of the type of prosthesis on the postoperative clinical outcome. Multiple linear models were constructed with the type of prosthesis, the preoperative relevant covariate and the covariates that reached the 0.2 significance level in the univariate model as independent predictors. All tests were two-sided at the 0.05 significance level, and all analyses were performed on R software (R is available as Free Software under the terms of the Free Software Foundation’s GNU General Public License).

RESULTS

The preoperative clinical evaluation of pain, function in daily activities, strength and mobility in the two groups are summarised in table I and the
postoperative results in table II. The difference between the preoperative and postoperative status was significant in the two groups ($p < 1.10^{-4}$). The Delta III prosthesis ended up with a superior postoperative Constant score and more postoperative strength ($p = 0.01$).

The radiological measurements of the lateral offset, the acromion-greater tuberosity distance and the acromion-humerus distance are summarised in table VI.
Scapular notching was noted in 32 patients in the Delta III prosthesis group. All scapular notchings were present at one year follow-up. At the last follow-up there were 11 grade 1, 11 grade 2, 9 grade 3 and 1 grade 4.

There was no scapular notching in the Arrow group, neither at one year nor at last follow-up.

Complications

There were seven complications in the Delta group. These included five cases of deep infection: three chronic infections were treated with removal of the prosthesis, placement of a bone spacer and revision after 3 months with a reverse prosthesis in two cases and hemiarthroplasty in one case. One other case was an acute post-operative infection, which was treated by arthrotomy and lavage without replacement of the prosthesis; the fifth case was treated by resection arthroplasty. Two cases of intra-operative glenoid fracture were treated by stabilisation with the metaglene.

In the Arrow group there were four early mechanical complications, all within the first year: disassembly of the glenosphere in three cases and dislocation of the humeral cup in one case. We revised three patients with a new glenosphere with a Morse taper and screw fixation (second generation) and one patient with a hemiarthroplasty. One of the revised patients developed an infection and was treated with a bone spacer after removing the implant, without further revision.

DISCUSSION

Modern shoulder arthroplasty introduced by Neer in the 1950s has demonstrated its clinical efficacy when used for the treatment of primary and secondary degenerative conditions of the shoulder with a functional rotator cuff.

In patients with a pseudoparalytic shoulder caused by a functionally ineffective or anatomically deficient rotator cuff and a deficiency of the coracoacromial arch, a condition initially described by Neer et al as “cuff tear arthropathy” (22), traditional designs of total shoulder arthroplasty components have lead to early failures. With these designs, the changing instant center of rotation and eccentric loading of the glenoid component (12,13,21), resulted in instability and unsatisfactory active mobility with early glenoid component loosening.

Since the 1970s, constrained and semiconstrained shoulder prostheses, such as the so-called reverse ball-and-socket design (31), have been used in the treatment of cuff tear arthropathies, but these prostheses were associated with high complication and revision rates (2,33). Early reverse shoulder prostheses (Gerard and Lannelongue, Kolbel, Kessel, Fenlin) (10,14,19,20) had a center of rotation outside the scapula; their functional results were poor, with high rates of failure due to glenoid loosening.

In the 1980s Grammont (15) introduced the Delta reverse shoulder prosthesis with satisfactory results in elderly patients with persistent shoulder pseudoparalysis due to an irreparable rotator cuff tear. In this prosthesis, the center of rotation is medialised, which increases the lever arm of the deltoid, and the humerus is distalised which increases the tension of the deltoid. Altogether, tensioning the deltoid and recruiting its anterior and posterior fibers can restore active anterior elevation and abduction when the rotator cuff is deficient. The design of this new semi-constrained prosthesis results in biomechanical conditions that decrease the incidence of the complications noted previously: absence of a glenoid neck and coverage of the baseplate by the glenosphere allow moving the center of rotation to the level of the glenoid and minimizing the shearing forces at the junction between the baseplate and the glenoid bone, which were mainly responsible for glenoid loosening.

Medialisation of the glenoid component with a fixed center of rotation allows restoration of active
anterior elevation but results in medialisation of the humerus and a potential impingement of the medial part of the humeral stem against the lateral pillar of the scapula. Medialisation of the humerus is also accentuated by the orientation of the humeral cup (155°). This orientation improves the stability of the reverse prosthesis as compared to the anatomical neck (135°), lengthens the fibers of the deltoid and improves deltoid strength. However, with this design, scapular notching appears soon after the operation and entails a potential risk of glenoid loosening on the long term (> 7 years) (17).

Scapular notching is a frequent complication with the Delta III reverse prosthesis: it was reported in 50% of cases by Vanhove et al (30) and in 63.6% by Sirveaux et al (28) (33.7% grade 1, 12.9% grade 2, 9% grade 3 and 7.8% grade 4). Notching can affect the Constant score when extensive and is worrisome for the future (9). In 2001, Valenti et al (29) reported a series of 59 reverse Delta prostheses: at follow-up greater than 7 years, 60% presented with scapular notching. In this series scapular notching was classified according to Nérot (29). This classification is useful to appreciate the evolution and the potential risk of fracture of the screw and secondary loosening. In grade 1 and 2, scapular notching does not progress and a densification appears at the level of the lateral pillar of the scapula, but in grade 3 and 4, scapular notching is progressive with polyethylene wear, chronic inflammation of the joint capsule and local osteolysis (23). Fibrous tissue may stabilize the metaglene (23) but osteolysis progresses to the metaphysis of the humerus, leading to a difficult revision procedure (figs 3 & 4).

To prevent scapular notching with the same implants (Delta-Tornier), some authors recommended to distalise the implantation into the glenoid of an inferiorly tilted glenosphere with a large diameter (42 mm) (8); but scapular notching may still appear if the prosthesis-scapular neck angle is high (18). Recently, Boileau et al (3) proposed to interpose a bone graft between the glenoid bone and the baseplate to prevent this scapular notching.

There was no scapular notching in this series of 49 patients managed with the reverse Arrow prosthesis. The absence of medial impingement could be explained by two differences in the design of the Arrow prosthesis: the first is that the glenosphere does not cover the metaglene and creates a 3.5 mm lateralisation of the center of rotation; the second difference is the shape of the Arrow humeral stem particularly of the metaphysis with an inclination of 135° which results in increased lateralisation of the humerus. In order to achieve stability similar to the
Delta III, the polyethylene cup is designed to obtain the same 155° inclination (fig 5).

Radiological analysis on the AP view in neutral position (table VI) showed that the Arrow prosthesis is more lateralised than the Delta III (5.4 versus 4.2cm) (p < 0.001). An important advantage of this lateralisation of the humerus is the reproduction of the anatomical contour of the shoulder on visual inspection (fig 6).

The position of the humerus on the craniocaudal axis is not significantly different between the two prostheses. The lever arm of the deltoid is similar in the two designs and respects the Grammont concepts. Frankle et al (11) made similar observations and found no scapular notching in a series of 60 patients managed with an other type of reverse prosthesis (ENCORE Medical, Austin, Texas, U.S.A.) designed with a more lateral center of rotation. Lateralisation of the center of rotation reproduces the normal lateral offset and preoperative shoulder contour; however in the series of Frankle et al (11) seven patients (12%) required revision for glenoid loosening at a mean follow-up of 21.4 months. They noted no bony ingrowth into the baseplate and the mode of failure appeared to be metal fatigue of the screws. They reported that the first two years after operation were critical and that the quality of the fixation of the baseplate is essential.

The design of the baseplate of the reverse Arrow prosthesis may explain the reduced incidence of early glenoid loosening: the prosthesis is available
in four sizes, it has a metaglene with a convex back surface that adapts perfectly to the normal curvature of the glenoid fossa. It also features a central keel and an anterior extension which ensure a primary press fit fixation to counteract shearing and torque forces during the first degrees of abduction. The metaglene is coated with hydroxyapatite on its deep surface, allowing for a better bony fixation. The two diverging screws (5.5 mm) with 15° of liberty (superior toward the foot of the coracoid and inferior toward the lateral pillar of the scapula), reproduce the initial fixation of the Grammont metaglene (16) to resist shearing forces (fig 7).

In a French multicentric retrospective study of 487 reverse Delta prostheses (1), active forward elevation, had increased by 59° (71 to 130°) external rotation by 4° and medial rotation by only one vertebral level. Sirveau et al (28) reported on 80 reverse Delta-III prostheses and found an 65° increase in forward elevation and 7.5° in external rotation (non significant). Frankle et al (11) reported a 50° increase in forward elevation, and 29.1° in external rotation.

In this study, we found a similar postoperative improvement in range of motion in the two groups (table V). This improvement was significant (p < 1.10-4) except for internal rotation in the Delta group (p = 0.1). Improvement in range of motion was more important in the Arrow group compared to the Delta group but this difference was not significant (p = 0.12 for ER1, p = 0.52 for ER2 and p = 0.31 for IR).

The reverse shoulder prosthesis can yield satisfactory and even spectacular results when used by an experienced shoulder surgeon (25). Even then however, the complication rates remain high, ranging from 13% to 50% (4,6,11,24,28,32). In our series, complication rates were 14.9% for the Delta group and 10.2% for the Arrow group. The lower postoperative strength observed with the Arrow prosthesis compared with the Delta prosthesis could be explained by the smaller medialisation of the center of rotation.

In summary, arthroplasty with the reverse shoulder prosthesis which respects Grammont’s concepts can restore active forward elevation of the arm in patients with glenohumeral osteoarthritis and severe rotator cuff deficiency (pseudoparalytic shoulder). Reduced medialisation of the center of rotation with lateralisation of the humerus and a good primary fixation of the metaglene can yield improvement in range of motion while avoiding scapular notching. Improvement in external and internal rotation is slightly better with the Arrow prosthesis, which may be more appropriate for elderly patient. While it is too early to predict the longevity of this prosthesis, absence of early scapular notching appears as a good predictive factor for absence of glenoid component loosening. A longer follow-up with more cases should confirm these early good results.

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