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ONLINE ARTICLES

Pyrocarbon interposition shoulder arthroplasty in young arthritic patients: a prospective observational study

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Background: We evaluated survival and midterm results of pyrocarbon interposition shoulder arthroplasty (PISA) in arthritic patients younger than 65 years.
Methods: Fifty-eight PISAs (InSpyre; Tornier-Wright, Bloomington, MN, USA), implanted in 56 patients between 2010 and 2015, were prospectively observed. The mean age at surgery was 52 ± 13 years. The cause was primary osteoarthritis (18), fracture sequelae (16), post–instability arthritis (15), aseptic necrosis (3), inflammatory disease (2), and failed hemiarthroplasty (4); 34 shoulders (61%) had previously undergone surgery. Glenoid erosion was assessed in 4 grades according to the Sperling classification. Humeral erosion was also assessed in 4 grades. Multivariate analysis was used to determine predisposing risk factors for both humeral and glenoid erosion.
Results: At a mean follow-up of 47 ± 15 months, survival rate was 90%. Six patients (10%) required conversion to reverse total shoulder prosthesis for painful glenoid erosion (n = 2) and humeral erosion with greater tuberosity stress fractures (n = 4). The mean Constant score and subjective shoulder value significantly increased from 36 ± 14 points to 70 ± 15 points and 32% ± 14% to 75% ± 19%, respectively ($P < .001$). Humeral medialization was observed in 78% of the cases with increased pain score. Uncorrected anteroposterior implant subluxation (12 cases) was associated with lower Constant score (50 points vs. 72 points; $P = .02$) and lower subjective shoulder value (53% vs. 78%; $P = .002$). On multivariate analysis, no risk factors for glenoid or humeral erosion were found.
Conclusion: At midterm follow-up, PISA does not protect from progressive glenoid erosion and can lead to greater tuberosity erosion and stress fractures. Longer follow-up is required to see whether PISA survival will be superior to that of hemiarthroplasty.
Level of evidence: Level IV; Case Series; Treatment Study
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Keywords: Shoulder; glenohumeral osteoarthritis; hemiarthroplasty; interposition arthroplasty; glenoid erosion; humeral erosion

The study was performed according to the medical ethical guidelines of our institution (approval reference: Study 2017-02). All patients were informed of the characteristics of this new implant and provided their consent to participate in the study.

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The treatment of glenohumeral osteoarthritis in younger patients (<65 years of age) is challenging.[39,40] The ideal material to resurface the glenohumeral joint in young arthritic patients has yet to be found, and there is an increasing demand for long-lasting implants in this active population.[13,24] Younger arthritic patients have high expectations and often have undergone previous operations. It is important for surgeons to take into consideration the risk of future revisions in their decision-making process.[10]

There is a lack of consensus regarding implant choice in the young arthritic shoulder.[1,38] The problem with total shoulder arthroplasty in young arthritic patients is the high rate of glenoid loosening (up to 50% at 10 years), which can lead to severe glenoid bone loss and complex revision procedures.[33] Biologic glenoid resurfacing, using meniscal allograft, capsular interposition, or synthetic membrane, has resulted in disappointing results. Reverse shoulder arthroplasty (RSA) is rarely indicated in younger patients because there are concerns about osteolysis and implant loosening in this active population.[11] The results of humeral resurfacing have been disappointing because of glenoid wear and cuff tears.[34] This is why hemiarthroplasty (HA) is often still favored in younger patients, although high rates of symptomatic glenoid erosion[40] (up to 21% at 5 years of follow-up) leading to revision have been reported.[6]

The concept of interposition arthroplasty has been conceptualized in the 19th century by Leopold Ollier, who proposed the interposition of fascia lata in different destroyed joints.[29] More recently, pyrocarbon[9,18-20] has been proposed for interposition arthroplasty and has proved to be effective in treating small arthritic joints at the wrist and hand level.[2,15,31,32] The main theoretical advantage of pyrocarbon[17] is that its modulus of elasticity is close to that of diaphyseal bone; pyrocarbon promotes the expression of type II collagen and can generate a cartilaginous matrix. The tissues in contact with the pyrocarbon are mineralized and homogeneous. The modulus of elasticity of the tissue developed on the surface of the pyrocarbon is more rigid than that in contact with cobalt-chromium, which confirms the biologic data.[17] An in vitro study showed that pyrocarbon in shoulder HA causes less bone wear in simulation of shoulder function compared with cobalt-chromium.[25] The question we sought to answer was, Can pyrocarbon interposition arthroplasty be used in larger joints and be an alternative to conventional prostheses for the young arthritic shoulder? The tribologic and elastic properties of such material, used with a nonfixed implant, could potentially reduce glenoid bone wear as well as prevent prosthetic loosening and the need for future revision.

The purpose of this study was to evaluate clinical and radiographic results of pyrocarbon interposition shoulder arthroplasty (PISA) with a minimum follow-up of 2 years in arthritic patients younger than 65 years at the time of surgery. We hypothesized that this new material, used with a spherical, nonfixed prosthesis, would reduce glenoid wear and revision compared with conventional HA.

Methods

Study design

We performed a prospective single-center study including 57 consecutive patients (59 shoulders) who underwent PISA (InSpyre; Tornier-Wright, Bloomington, MN, USA). All patients were operated on by the senior author (P.B.) between June 2010 and December 2015 and were prospectively observed. We included all patients reviewed with minimum follow-up of 2 years. Only 1 patient with incomplete follow-up was excluded, leaving 56 patients (58 shoulders) for final analysis. Patients were observed on a yearly basis, and the standard anteroposterior and lateral radiographs and computed tomography (CT) scans were reviewed by 2 independent observers. The mean age at surgery was 52 ± 13 years, and 31 patients (55%) were active men. Thirty-three patients practiced sports before symptoms, and 1 patient was a professional windsurfer. The epidemiology is summarized in Table I.

Preoperatively, the rotator cuff tendons were intact in all patients. No fatty muscle atrophy of any rotator cuff muscles greater than Goutallier grade 2 was confirmed with CT scan or magnetic resonance imaging. The glenoid morphology was determined on the basis of the modified Walch classification.[43] The glenoid wear was concentric in 34 patients (Walch type A1 in 26 patients and type A2 in 8 patients), and there was a posterior subluxation in 24 patients (Walch type B1 in 11 patients and type B2 in 13 patients). Patients operated on for fracture sequelae included 14 patients with type 1, 1 patient with type 2, and 1 patient with a type 4 fracture sequelae according to the Boileau classification.[5] Thirty-four patients (59%) had previously undergone surgery (Table II).

Surgical technique

A standard deltopectoral approach was used for all patients under general anesthesia associated with interscalene nerve block. The subscapularis tendon was detached from the lesser tuberosity using a peel-off technique and reattached with nonabsorbable transosseous sutures at the end of the procedure. Biceps tenodesis was performed in all cases. After humeral osteotomy at the anatomic neck level, spherical reaming of the proximal humerus was performed with reamers of increasing diameter. The diameter of the reamers and implants varied between 36 mm and 44 mm, with an average of 40 mm. The cancellous bone harvested with the reamers was reimpacted in the proximal metaphysis just before implant positioning. Associated concentric reaming of the glenoid was performed in 22 patients (37%). In 16 patients with a biconcave (Walch type B) glenoid, this reaming was performed in an attempt to correct excessive retroversion (by lowering the high side) and to recenter the humeral head. In 6 patients with a concentric (type A) glenoid, the reaming was performed to smooth the arthritic articular surface. The reaming technique involves using the reamers of the

Table I Epidemiology

	N = 56 (%)
Age (yr)	52 ± 13
Sex, female/male	25/31
Dominant side	35 (62)
ASA class	
1	31 (56)
2	20 (36)
3	5 (9)
Medical comorbidities	
Tobacco use	11 (20)
Diabetes	0
Epilepsy	1 (2)
Previous surgery	34 (61)
Professionally active (heavy manual labor)	46
Manual labor	25
Retired	11
Sport participation before symptoms	33
Diagnosis	
Primary glenohumeral osteoarthritis	18
Fracture sequelae	16
Instability arthropathy	15
Revision of failed hemiarthroplasty	4
Aseptic osteonecrosis	3
Rheumatoid arthritis	2

ASA, American Society of Anesthesiologists.
Categorical variables are presented as number (%). Continuous variables are presented as mean ± standard deviation.

Perform glenoid (Tornier-Wright). To guide the reamer, a threaded K-wire was inserted in the center of the glenoid with the desired retroversion using a specific guide. Three glenoid reamers with different radius of curvature are available for each size of glenoid (small, medium, large, and extra-large). We used the most convex glenoid reamer, adapted to the glenoid size, to re-create a dish that will stabilize the spherical implant. Then, using the K-wire, small holes were drilled on the glenoid surface to release the frequent subchondral hyperpression seen in osteoarthritis for relief of pain and to obtain some bone bleeding in the hope that it could contribute to restoration of some glenoid fibrocartilage. All patients were immobilized in a neutral rotation sling for 4 weeks. They were allowed to remove the brace to perform a self-education program with pendulum exercises (5 times a day, 5 minutes for each session), starting the day after surgery. Conventional physiotherapy and swimming pool therapy were started after 4 weeks.

Clinical assessment

Patients were prospectively followed up at 45 days, 3 months, 6 months, and then each year. The clinical assessment includes measurement of active range of motion, evaluation of pain according to the visual analog scale, and Constant-Murley score.[8] The subjective result was assessed using the subjective shoulder value (SSV).[16] In addition, patients were asked at the last follow-up about return to work and sports and overall satisfaction. For each patient, we registered the level of physical activity at work or in sports.

Table II Details of previous surgeries

Previous surgery	No. of patients (%)
Arthrolysis–biceps tenodesis	4 (12)
Stabilization procedure	15 (44)
Arthroscopic Bankart	8
Open Latarjet	4
Posterior bone block	1
Metallic bone block	1
Fracture fixation	11 (32)
Nail	4
Plate	5
Screws	3
Previous failed hemiarthroplasty	4 (12)
Total	34/58 (59)

Radiologic assessment

Glenoid erosion was assessed using the method proposed by Sperling et al.[41] It was labeled none (grade 1), mild (grade 2: erosion into subchondral bone), moderate (grade 3: hemispheric deformation with medialization), or severe (grade 4: spherical deformation until/beyond the base of the coracoid). We were looking for the presence of cyst preoperatively.[21]

Humeral erosion was also assessed in 4 grades: 1, none (greater tuberosity [GT] densification); 2, mild (GT erosion without humeral densification); 3, moderate (GT thinning); and 4, severe (spherical deformation reaching the lateral cortex or GT fracture). We measured the preoperative and postoperative thickness of the GT and researched the spherical GT deformation as well as humeral densification around the pyrocarbon implant (Fig. 1).

Medialization of the implant was measured by comparing the ratio between *a*, the distance of the center of the implant and the lateral edge of the acromion, and *b*, the radius of the implant, right after surgery and at last follow-up (Fig. 2).

Proximal migration of the implant was measured by comparing the acromiohumeral distance on the immediate and the last postoperative anteroposterior radiographs.[28]

Osteoporosis was assessed by measuring the cortical thickness of the humeral diaphysis by the Tingart index.[42] We also measured glenoid inclination in the frontal plane with the beta angle.[27]

CT scan assessment

The presence and percentage of humeral head subluxation, according to the Friedman line, were analyzed in the horizontal plane on CT scan, both before surgery and at final follow-up; 100% corresponded to complete posterior dislocation, 0% to an anterior dislocation. An index between 45% and 55% represented a centered implant.[4,12,36] The humerus was considered to be posteriorly subluxated when the index was >55%. The axial cut, located at the equator level, is recommended to calculate humeral head subluxation.[12,34] However, to be more objective because we observed some implant upward migration with time, we chose the axial slice of the implant's largest diameter to calculate the degree of humeral subluxation (instead of the axial cut of the equator). We also measured the version of the glenoid, and we used an

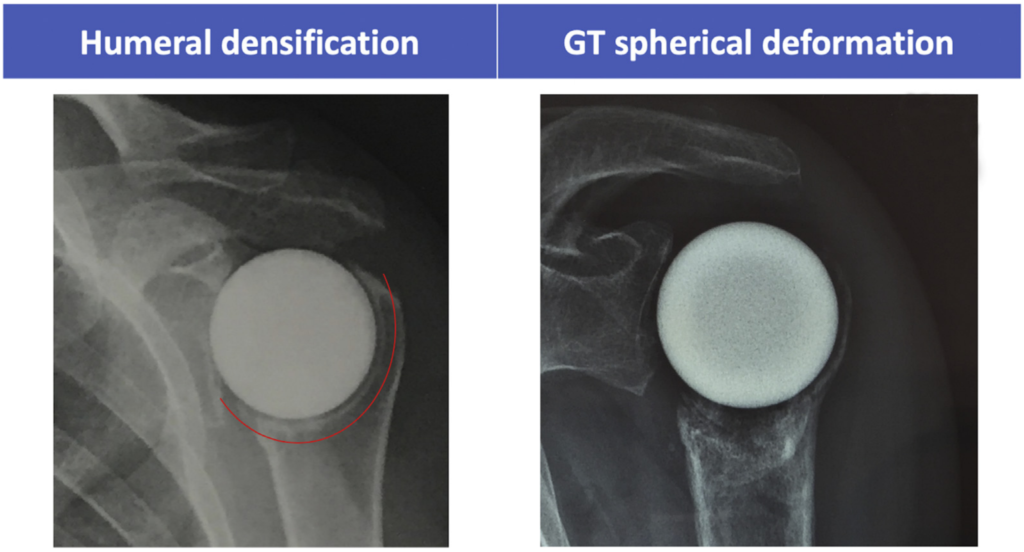

Figure 1 Humeral densification. *Left*, The increased density of the humerus parallel to the —— is perfectly visible. *Right*, Greater tuberosity (*GT*) spherical deformation is defined by reaching the external cortex on radiograph at last follow-up.

intermediate glenoid line in B2 glenoid.[36] Two observers independently examined radiographs and CT scans twice with a minimum of 1 week between the 2 assessments.

Statistical analysis

Quantitative variables were analyzed by the Mann-Whitney and Wilcoxon tests. The χ^2 and Fisher tests were used for analysis of qualitative variables. The value of $P < .05$ was considered statistically significant. The survival analysis was estimated according to the Kaplan-Meier method; the end point was the occurrence of arthroplasty revision. To assess reproducibility of measurements, Cohen κ is evaluated (inter-rater and intra-rater reliability). The κ coefficient ≤ 0 indicated no agreement; 0.01-0.20, none to slight agreement; 0.21-0.40, fair agreement; 0.41- 0.60, moderate agreement; 0.61-0.80, substantial agreement; and 0.81-1.00, almost perfect agreement. Glenoid and humeral erosion were analyzed for cofounding factors (age of patients, sex, Tingart index, reaming, and size of humeral head) using a multivariate analysis. Statistical analysis was performed using RStudio, version 1.1.463.

Results

Prosthesis survival

At a mean follow-up of 47 ± 15 months, 6 patients (10%) required revision surgery (Fig. 3). The initial diagnosis was primary glenohumeral osteoarthritis in 4 cases, type 2 fracture sequelae in 1 case, and instability arthropathy in 1 case. The main cause for revision was shoulder pain and impairment related to glenoid erosion. Isolated glenoid erosion was found in 2 patients and associated with severe GT erosion with fractures (stress fractures in 2 patients and after minor trauma in 2 other patients). The delay between

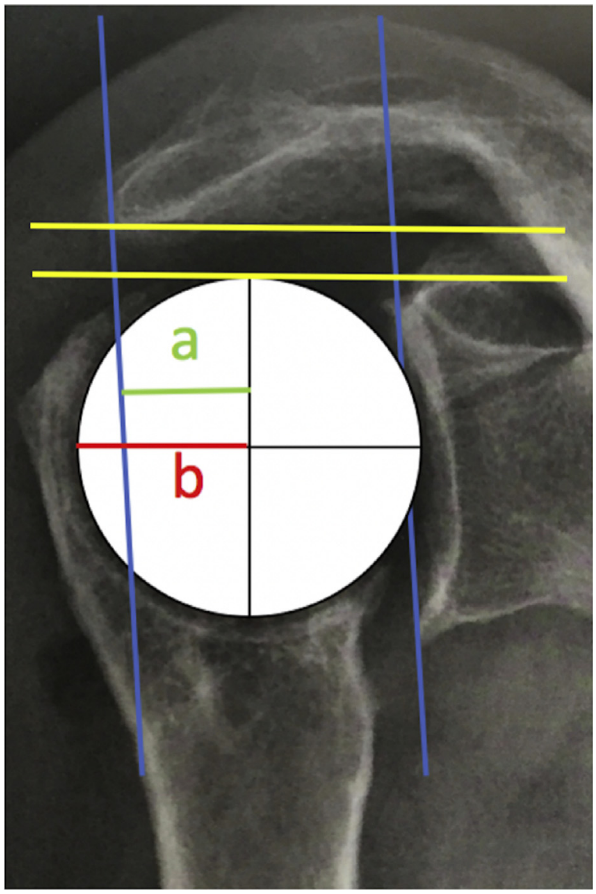

Figure 2 Calculation of medialization: *a*/*b* postoperative ratio minus *a*/*b* ratio at last follow-up. If it is negative, this corresponds to a medialization. The —— represent the method used to measure the acromiohumeral distance relative to the diameter of the implant.

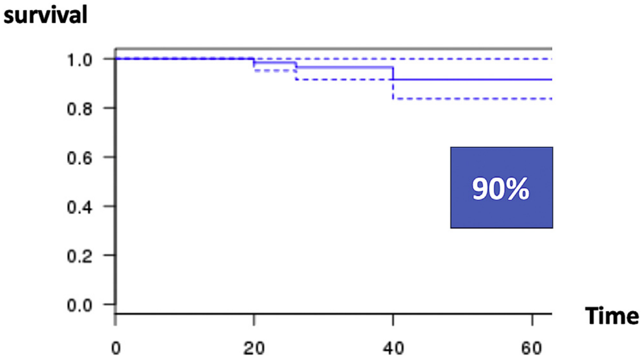

Figure 3 Revision-free survival of pyrocarbon interposition shoulder arthroplasty.

primary surgery and revision was 38 ± 15 months (range, 20-60 months).

Complications and revision

Complications and revision surgery are detailed in Table III.

Two patients were reoperated on for persistent shoulder stiffness and pain without revising the implant. The first patient, operated on for glenohumeral arthritis secondary to anterior instability, underwent open arthrolysis 10 months after PISA. The second patient had an arthroscopic acromioplasty 18 months after the index surgery for cuff tendinitis. Both patients had improved shoulder function (Constant score of 76 points and 79 points, respectively) at last follow-up.

Six patients (10%) required revision surgery, 2 because of painful glenoid erosion and 4 because of glenoid erosion combined with GT erosion and fractures. The GT fracture was related to a trauma in 2 patients, whereas it occurred spontaneously in the other 2 patients (Fig. 4).

Patients were revised to RSA after impaction of cancellous bone allograft (Osteopure, OST Développement, Clermont-Ferrand, France) in the proximal humerus. GT healing was achieved, and functional results after RSA were satisfactory with a mean Constant score of 78 ± 7 points. The 2 patients with isolated glenoid erosion were also revised to RSA. An allograft of the glenoid was used to correct for severe medialization (Fig. 4). At last follow-up, the functional result was satisfactory with a Constant score of 81 points in one patient and 65 points in the other.

Functional outcomes

The functional results were evaluated on the 52 shoulders with the implant in place at last follow-up. As shown in Table IV, all the parameters of the Constant score and active range of motion improved significantly.

Table III Complications and reoperations

Postoperative complications	No.	Revisions/reoperations
Postoperative greater tuberosity fracture	4	4 (reverse shoulder arthroplasty)
Painful glenoid wear	2	2 (reverse shoulder arthroplasty)
Persistent shoulder stiffness	2	2 (arthrolysis)

Subjective outcomes

Overall, 90% of patients were satisfied or very satisfied with the procedure. The mean SSV increased significantly from 32% ± 14% to 75% ± 19% ($P < .001$). The return to work rate with or without adaptation was possible for 90% of the patients, and 82% were able to return to sports at the same or lower level.

Glenoid erosion

We compared Sperling grades 1 and 2 vs. grades 3 and 4 (Table V). No risk factors were found on multivariate analysis.

Humeral erosion

We compared Barret grades 1 and 2 vs. grades 3 and 4 (Table VI). No risk factors were found on multivariate analysis.

Humeral medialization

When the GT was medialized compared with the acromion, the Constant pain score was worse, 11.4 vs. 13 ($P = .03$).

Risk factors for proximal migration of the implant

No risk factors were found on multivariate analysis.

Implant medialization

In the frontal plane, implant upward migration (67% of cases), GT thinning (78%), and glenoid erosion (78%) were noted frequently (Fig. 5). Of 45 patients who had glenoid erosion, 35 (78%) had a medialized implant compared with only 2 patients of 13 (15%) without glenoid erosion; this result is statistically significant ($P < .001$).

Anteroposterior humeral subluxation

At a mean follow-up of 46 ± 14 months, CT scan analysis revealed 5 anterior subluxations (9%) and 7 posterior subluxations (12%), whereas the sphere was centered in the glenoid in 46 cases (Fig. 6). Static anterior subluxations were associated with a subscapularis insufficiency: 2

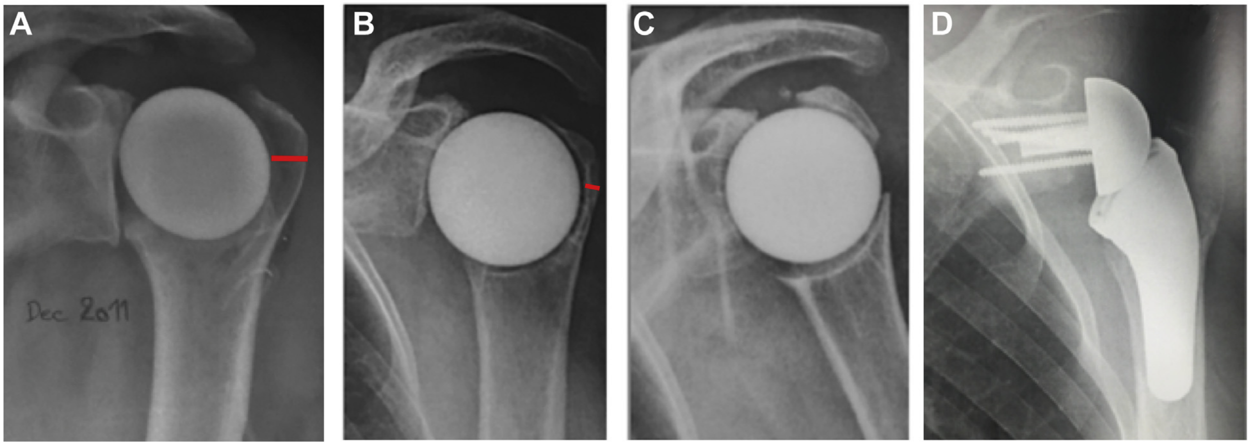

Figure 4 Sequential anteroposterior radiographs of a 59-year-old patient operated on for primary glenohumeral osteoarthritis. (**A**) Bipolar bone erosion (glenoid and greater tuberosity [GT]). (**B**) Progression to spontaneous GT thinning and fracture that occurred at 2½ years. (**C**) Revision to reverse shoulder arthroplasty with impaction of allograft on the glenoid and in the humeral metaphysis (cerclage of the GT with looped sutures). (**D**) GT thinning**.** When we compared radiographs during follow-up, thinning of the GT was >1 mm between 2 successive radiographs. In the example, the ——— shows the gradual thinning of >1 mm of the GT by performing a calculation with the size of the diameter of the implant.

Table IV Functional results and active mobility

	Preoperative	Final follow-up	Gain	*P*
Pain (points)	6 ± 3	13 ± 3	7 ± 4	<.001
Activity (points)	8 ± 4	16 ± 4	8 ± 5	<.001
Mobility (points)	14 ± 7	29 ± 8	15 ± 11	<.001
Strength (points)	6 ± 5	12 ± 6	6 ± 5	<.001
Absolute Constant (points)	36 ± 14	70 ± 15	34 ± 20	<.001
Adjusted Constant (%)	37 ± 15	74 ± 16	37 ± 21	<.001
Active forward elevation (degrees)	93 ± 23	143 ± 25	50 ± 31	<.001
Active external rotation (degrees)	7 ± 17	36 ± 17	29 ± 21	<.001
Active internal rotation (points)	3 ± 2	6 ± 2	3 ± 2	<.001

Values are presented as mean ± standard deviation.

Table V Glenoid erosion classification with method of Sperling

Glenoid erosion	No.	%	Glenoid cyst
Grade 1 (no erosion)	13	22	1
Grade 2 (erosion into subchondral bone)	24	42	2
Grade 3 (spherical deformation with medialization)	18	31	16
Grade 4 (medialization reaching the coracoid or beyond)	3	5	3

Table VI Humeral erosion classification with a new method (Barret classification)

Humeral erosion	No.	%
Grade 1 (GT densification)	13	22
Grade 2 (GT erosion without humeral densification)	17	29
Grade 3 (GT thinning)	18	32
Grade 4 (spherical deformation reaching the lateral cortex or GT fracture)	10	17

GT, Greater tuberosity.

patients suffered a traumatic subscapularis rupture; in 2 patients, there was a stage 2 fatty infiltration of the subscapularis muscle; and 1 patient had a nonunion of a lesser tuberosity lesion.

Seven cases of persistent posterior subluxation (12%) were identified; no glenoid reaming was performed. In these cases, there were 3 patients with primary glenohumeral osteoarthritis, 3 patients with instability arthropathy, and 1 patient with prosthetic revision.

A significant difference was found in pain score (12.7 points vs. 9.1 points; $P = .03$), Constant score (72 points vs. 50 points; $P = .028$), and SSV (78% vs. 53%; $P = .0024$) between patients with a centered and noncentered sphere. When the implant was centered, no difference was found in

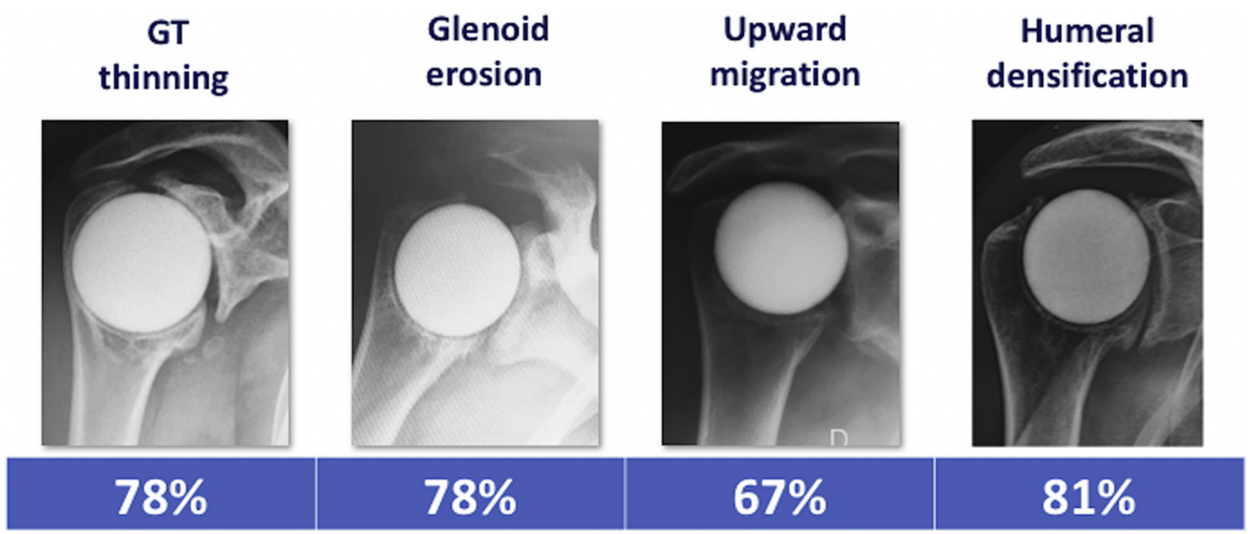

Figure 5 Horizontal plane with radiographic results at last follow-up.

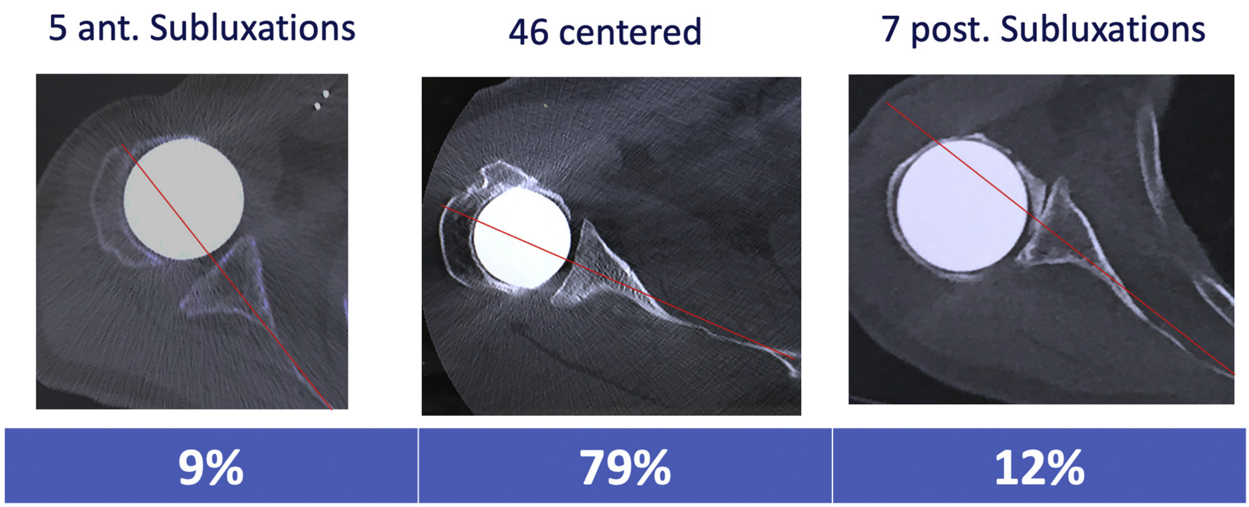

Figure 6 Axial computed tomography position of pyrocarbon interposition shoulder arthroplasty at last follow-up.

clinical and functional outcomes between patients with and without reaming.

Intraobserver and interobserver outcomes

Intra-rater reliability is excellent (intraclass correlation coefficients between 0.86 and 1) for all parameters. Inter-rater reliability is moderate for preoperative axial plane evaluation ($\kappa = 0.587$; Tables VII and VIII).

Role of concentric glenoid reaming

Concave glenoid reaming was performed in 22 patients (37%), 6 patients with type A glenoid and 16 patients with type B glenoid. There was no statistically significant association between reaming and glenoid erosion. Of the 24 patients with a type B glenoid, 16 patients (67%) underwent concentric glenoid reaming. At final follow-up, in 15 of these patients, the implants (94%) were centered. Eight patients with type B glenoid had not undergone any reaming. Only 3 of the 8 cases had a centered implant at final follow-up. The difference was significant between the patients having undergone reaming or no reaming ($P = .018$). The mean correction of retroversion of the glenoid surface achieved was $6° \pm 4°$ ($P = .000257$) for all patients with type B glenoid. The glenoid inclination in the frontal plane was 78.1° preoperatively and 77.3° postoperatively, calculated according to the beta angle.[27] No difference was found between reaming and no reaming groups preoperatively and postoperatively: 77.9° and 77.2° preoperatively and postoperatively for the reaming group vs. 78.5° and 76.9° for the reaming group.

Table VII Inter-rater reliability between 2 raters (senior and resident) using unweighted Cohen κ

Two Raters (senior and resident)	Agreement (%)	Expected agreement (%)	κ	95% Confidence interval
Centered humeral head D1	79.7	100	0.587	0.38-0.80
Centered humeral head D8	79.7	100	0.587	0.38-0.80
Centered prosthesis D1	96.6	100	0.895	0.75-1.03
Centered prosthesis D8	96.6	100	0.895	0.75-1.03
Vertical plane D1	91.5	100	0.782	0.60-0.96
Vertical plane D8	86.4	100	0.626	0.39-0.87
Glenoid erosion D1	94.9	100	0.863	0.71-1.01
Glenoid erosion D8	88.1	100	0.645	0.40-0.89
Upward migration D1	89.8	100	0.767	0.59-0.93
Upward migration D8	89.8	100	0.76	0.58-0.94
Humeral densification D1	91.5	100	0.761	0.56-0.96
Humeral densification D8	88.1	100	0.667	0.43-0.90

Table VIII Intra-rater reliability (senior and resident) using unweighted Cohen κ

One rater	Agreement (%)	Expected agreement (%)	κ	95% Confidence interval
Centered humeral head D1/D8, senior	100	100	1	1-1
Centered humeral head D1/D8, resident	100	100	1	1-1
Centered prosthesis D1/D8, senior	100	100	1	1-1
Centered prosthesis D1/D8, resident	100	100	1	1-1
Vertical plane D1/D8, senior	98.3	100	0.95	0.86-1.04
Vertical plane D1/D8, resident	96.6	100	0.91	0.80-1.03
Glenoid erosion D1/D8, senior	98.3	100	0.95	0.86-1.04
Glenoid erosion D1/D8, resident	94.9	100	0.86	0.70-1.01
Upward migration D1/D8, senior	100	100	1	1-1
Upward migration D1/D8, resident	96.6	100	0.92	0.82-1.03
Humeral densification D1/D8, senior	98.3	100	0.96	0.87-1.04
Humeral densification D1/D8, resident	98.3	100	0.95	0.84-1.05

Discussion

Glenoid erosion remains one of the main concerns in shoulder HA, specifically in a young active population, and it is the main reason for early revision.[35,39,40] The main finding of this study is that implantation of PISA in arthritic patients younger than 65 years does not prevent glenoid erosion and can also lead to humeral erosion. Our hypothesis is not verified. Although good functional outcomes have been observed at midterm follow-up, overall survival of PISA (90% at a mean of 3.9 years) is not better than that reported for conventional HA. Pyrocarbon, used with a spherical nonfixed prosthesis, does not reduce glenoid wear and can lead to severe GT erosion, causing stress fractures and revision.

The fact that pyrocarbon, used as an interposition implant, could cause severe and rapid glenoid erosion was unexpected. The rate of glenoid erosion observed (78% at midterm follow-up) with PISA is similar to that seen with conventional HAs with metallic heads. Two patients of 56 had to be revised because of painful glenoid erosion. The occurrence of severe and rapid GT erosion after PISA was even less expected. Thinning of the GT was observed in 78% of the cases, resulting in GT stress fractures in 2 patients and after minor trauma in 2 other patients of the series that needed to be revised. The majority of the glenoids in the series had preoperative wear, with more than half of them being remodeled pathologically. The degree of glenoid erosion can be influenced by the state of glenoid preoperative disease as well as by reaming. Unfortunately, no risk factor for glenoid or GT wear was identified in univariate or multivariate analysis. Although reaming of the glenoid may also cause premature wear, this was not verified in our series. The modulus of elasticity of pyrocarbon is close to that of diaphyseal bone and more favorable than that of metal.[14,17,22] However, the spherical pyrocarbon implant, being in contact with the cancellous bone of the GT, could explain the important and progressing bone wear observed on the humeral side.

Garret et al[14] published the first series of PISA. The authors found a survival rate of 89.2% at an average follow-up of 49.7 months extracted from the sponsor's monitoring register. All clinical parameters had improved significantly at 26.8 months. The majority of patients were treated for primary glenohumeral osteoarthritis (58%). The rate of encountered glenoid wear and thinning of the GT were much lower, 11% and 5%, respectively. This may be explained by a shorter follow-up (27 months) compared with our study. Subsequently, Hudek et al[23] presented a series of 10 PISAs after type I fracture sequelae and normal glenoid with an average follow-up of 42 months. No revisions were reported. The radiologic analysis identified the presence of significant osseous changes. They found glenoid erosion in 9 patients, thinning of the GT in 6 patients, superior migration of the humeral head in 8 patients, and increased bone density around the implant for all patients. The corticalized aspect of the upper extremity of the humerus in post-traumatic arthritis may explain the absence of GT fracture. Excessive intraoperative humeral reaming may also cause premature wear, but this was not proven in our series.

Similar to what has been observed with conventional arthroplasties,[3,22,30] Garret et al[14] have found that PISA in patients with eccentric glenoid wear (Walch types B and C) had inferior outcomes compared with those with concentric wear; they concluded that eccentric glenoid wear with humeral subluxation is a contraindication to PISA. In this study, we also found that persistent or uncorrected posterior subluxation of the humeral implant after PISA is a cause of persistent shoulder pain and revision. However, an important finding of our studies, brought by our CT scan study, is that concentric glenoid reaming allows correction of the glenoid retroversion and enables centralization of the humerus in patients with posteriorly eroded (Walch types B and C) glenoids. In our series, pain score, Constant score, and SSV were significantly better in the centered group compared with the noncentered group. These results are supported by previous studies with a shorter follow-up in which glenoid reaming was combined with HA.[7,26,37] However, longer follow-up studies are needed to confirm the promising results observed after a reaming procedure for biconcave or dysplastic glenoids.

Several limitations of our study need to be addressed. It is a single-arm study in a single center with one experienced surgeon. This study includes patients with various types of primary disease. Therefore, patient volume in subgroups was limited, which provided difficulties with thorough statistical analysis, and there is a risk of type II error. The main strength of our study was its prospective design. In addition, axial plane analysis of the implant position with CT scans has not been previously reported. Finally, the radiologic and CT scan analyses were performed by 2 independent observers with satisfactory interobserver and intraobserver correlation.

Conclusion

In young arthritic patients (mean age, 52 years), survival rate of PISA is 90% at a mean of 4 years. Glenoid and humeral bone erosion is the main cause of surgical revision. In case of type B glenoid, persistence of humeral subluxation is a cause of persistent shoulder pain and revision. Associated concentric glenoid reaming allows recentering of the humerus and good functional results. Further long-term studies are needed to better understand bone remodeling and erosion on both the glenoid and humeral side and to draw further conclusions on the applicability of this new interposition arthroplasty concept.

Disclaimer

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