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Scientific Articles
Observational Studies

Five-Year Radiographic and Clinical Outcomes of Pyrocarbon Hemiarthroplasty for Glenohumeral Arthritis and Osteonecrosis

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Investigation performed at Western Orthopaedics, Denver, Colorado, and 3D Shoulder, LLC, Minneapolis, Minnesota

Background: This study evaluated the progression of humeral head medialization in patients who underwent pyrocarbon hemiarthroplasty (PyC-HA). The authors hypothesized that glenoid erosion would not dramatically progress between the short-term and final imaging evaluations, and that there would be excellent clinical outcomes at ≥5-year follow-up.

Methods: Patients who underwent PyC-HA with ≥60 months of follow-up were included in this prospective study. Relevant data included preoperative demographic characteristics, Walch glenoid classification, changes in clinical outcomes, and revision-free and failure-free survival rates. An investigator, who was blinded to patient outcomes, assessed the glenoid morphology, changes in medialization, joint space, acromiohumeral distance (AHD), critical shoulder and β angles, and posterior subluxation in decentered glenoids at the 2-year and final follow-up visits.

Results: Forty-five patients with a mean age of 52 years and a mean follow-up of 73 months met the inclusion criteria. Significant improvements were observed across all outcome measures. The 7-year revision-free survival rate was 95.7%. Posterior subluxation in decentered shoulders decreased from 27.1% preoperatively to 19.8% postoperatively ($p = 0.008$). The mean medialization of the humeral head was 2.9 ± 2.8 mm at the 2-year follow-up and increased to 4.0 ± 3.3 mm at the time of the final follow-up ($p = 0.096$). A >2-mm decrease in AHD from early postoperative to final imaging was observed in 82.2% of patients ($p < 0.001$). All other radiographic changes were not significant.

Conclusions: PyC-HA is a reliable procedure for treating glenohumeral joint disease, demonstrating excellent clinical outcomes and stabilized glenoid morphology in the majority of patients between the 2-year and intermediate-term follow-up.

Level of Evidence: Therapeutic Level II. See Instructions for Authors for a complete description of levels of evidence.

Managing glenohumeral arthritis in patients with high-demand shoulder activities requires consideration of a patient's expectations regarding their functional and long-term outcomes, and the choice of procedure requires careful consideration of complications. In younger patients, polyethylene glenoid resurfacing has been shown to progress to aseptic loosening, leading to a decline in outcomes and the need for revision[1-3]. Reverse total shoulder arthroplasty is typically reserved for older patients, does not always provide optimal motion, and limits the options for revision[4], which are important considerations for the active patient population[2]. Humeral head resurfacing hemiarthroplasty (HA) was introduced to improve the anatomic reconstruction of the humeral head compared with that achieved using stemmed HA[5]; however, high rates of dissatisfaction and revision surgery due to continued pain have been reported[6-8]. Cobalt-chromium (CoCr) HA with glenoid reaming has shown improved outcomes compared with resurfacing HA, albeit with reports of prolonged postoperative pain and higher rates of subsequent operative procedures[9-13].

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Pyrocarbon (PyC)-on-graphite composites have emerged as an alternative bearing surface because of their low-friction surface, favorable boundary-lubrication properties, and biomechanical similarity to cortico-cancellous bone[14]. These factors could mitigate the glenoid erosion and pain commonly seen with CoCr HA. The purpose of this study was to objectively evaluate the progression of humeral head medialization from the short term to the intermediate term and to assess whether medialization impacts outcomes in patients who had undergone PyC-HA. The authors hypothesized that glenoid erosion would not dramatically progress between the short-term and final imaging evaluations, and that there would be excellent clinical outcomes at ≥5-year follow-up.

> *This study demonstrated that PyC-HA is a reliable treatment method for patients with glenohumeral arthritis, providing excellent improvement in PROMs while demonstrating an acceptable rate of humeral head medialization and a high rate of implant survival at intermediate-term follow-up.*

Materials and Methods

The study cohort was identified from the patients of 2 fellowship-trained shoulder surgeons who participated in the Stryker Pyrocarbon Hemiarthroplasty Investigational Device Exemption (IDE) protocol, which was completed in July 2019. The cohort included patients with at least 5 years of clinical and radiographic follow-up through their participation in a subsequent, institutional review board-approved prospective PyC-HA follow-up study. Preoperative demographics, Walch glenoid classification, and intraoperative glenoid preparation were sourced from the IDE study. Neither race nor ethnicity data were collected as part of the IDE study. Patient-reported outcome measures (PROMs), including the American Shoulder and Elbow Surgeons (ASES) score, Single Assessment Numeric Evaluation (SANE) score, Constant score, pain (on a scale of 0 to 10), patient satisfaction, and perception of health status, as well as goniometer-measured active range of motion (aROM), were obtained at baseline, 24 months, and final follow-up and were assessed for changes. A Kaplan-Meier analysis was performed to determine revision-free and failure-free survival (with failure defined as dissatisfied or very dissatisfied and/or an ASES score of <50 at the time of final follow-up).

Radiographic Assessment

Radiographs were standardized to ensure proper visualization of the glenohumeral joint and the lateral acromion while maintaining neutral rotation of the humerus on the Grashey true-anteroposterior (AP) view. One investigator, blinded to patient outcomes, utilized the GNU Image Manipulation Program (GIMP Development Team) and Fusion 360 software (Autodesk) to evaluate the true-AP radiographs. The use of this software allowed for consistent vertical alignment and the identification of anatomical landmarks (Fig. 1-A).

The investigator assessed humeral head medialization according to the method described by Somerson et al., measuring the distance between the center of rotation of the humeral head and a vertical line from the tip of the acromion[15]. The acromiohumeral distance (AHD), joint space, critical shoulder angle (CSA), and β angle were all measured using methods previously described in the literature[16-18].

The PyC humeral head appears slightly smaller on radiographs than it actually is due to the radiolucency of the layer of PyC material covering the radio-opaque graphite nucleus. To address this, the magnification coefficient was calculated using the ratio between the manufacturer-provided diameter of the tray under the PyC shell and the measured tray diameter. Multiplying the measured distance by this coefficient yielded corrected linear measurements.

The short-term findings compared early postoperative (1 to 6-week) and 24-month radiographs, whereas the final measurements reflected changes from early postoperative to final imaging. Final measurements were categorized by clinical relevance (Figs. 1-B and 1-C). Medialization was classified as severe (>10 mm), moderate (>5 mm to ≤10 mm), mild (>2 mm to ≤5 mm), minimal (>0 to ≤2 mm), or none (≤0) (Fig. 1-B). Joint space change was evaluated in patients with osteonecrosis. A fellowship-trained shoulder and elbow surgeon, who was blinded to the outcomes, assessed the posterior decentering of the humeral head in patients with Walch type-B glenoids with use of the Iannotti and Norris method[19].

Surgical Technique

The 2 surgeons performed PyC-HA using a deltopectoral approach, with the subscapularis released via lesser tuberosity osteotomy and tenodesis of the long head of the biceps. The humeral head was osteotomized at the anatomic neck using local landmarks after removing osteophytes, and the metaphysis was prepared for the correct stem size. If a glenoid had minimal cartilage damage, it was left unaltered. For concentrically worn glenoids, the surface was lightly abraded with a burr and microdrilled. For glenoids with eccentric wear, reshaping with a motorized burr (i.e., glenoidplasty) and, rarely, with a reamer (2 patients) was performed at the surgeon's discretion to correct biconcavity, to adjust version, and to ensure a smooth-surfaced humeral head articulation. The glenoid surface was typically treated

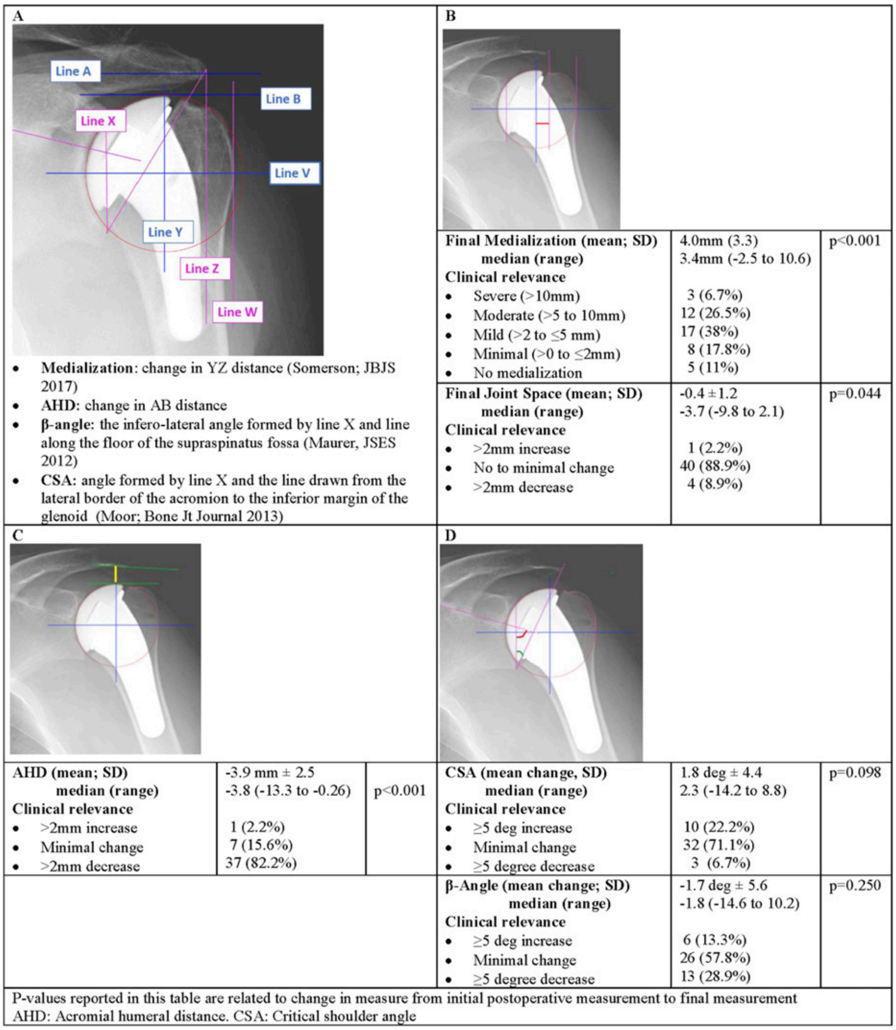

Fig. 1

Fig. 1-A: The landmark lines that were applied to all images to obtain relevant measures. **Fig. 1-B:** The red line represents the YZ measurement used in assessing medialization. **Fig. 1-C:** AHD as measured by the AB distance (yellow line). **Fig. 1-D:** CSA (green line) and β angle (red line).

using a 1.5-mm drill or microfracture to stimulate bleeding and fibrocartilage formation. After determining the PyC humeral head size, the final humeral stem and PyC head were placed. Shoulder stability and mobility were tested post-reduction and after the subscapularis repair. The standard shoulder arthroplasty postoperative protocol of the authors included sling protection for 6 to 8 weeks and passive motion for the first 3 to 4 weeks followed by active assistive motion and then active motion at 6 to 8 weeks, with heavy lifting restricted for 4 to 6 months.

Statistical Analysis

Continuous variables were analyzed using the Welch paired t test, and categorical variables were analyzed using the Fisher exact test. Significance was defined as $p < 0.05$. The Pearson correlation was used to assess the relationship between radiographic measures and clinical outcomes, with correlations defined as negligible ($r = 0.00$ to 0.29), low ($r = 0.30$ to 0.49), moderate ($r = 0.50$ to 0.69), high ($r = 0.70$ to 0.89), or very high ($r = 0.90$ to 1.00)[20]. Multiple regression was conducted to determine whether age, sex, prior surgery, surgical indication, Walch type, or glenoid treatment was predictive of medialization. The data analysis was performed using RStudio (Posit Software), and a post hoc power analysis demonstrated that the study had 80% power to detect a 2.0-mm change in medialization.

Results

Of 54 patients who were eligible for the study, 45 met the inclusion criteria (Fig. 2), with a mean follow-up time of 73 months (range, 61 to 92 months). Table 1 provides a summary of the cohort demographics. The analysis comparing outcomes between the initial preoperative visit and the 2-year and ≥5-year follow-up visits revealed significant improvements in all aROM measures and PROMs ($p < 0.001$), exceeding the established minimal clinically important difference for the ASES, Constant, SANE, and visual analog scale (VAS) pain scores[21,33]. At the time of final follow-up, male and

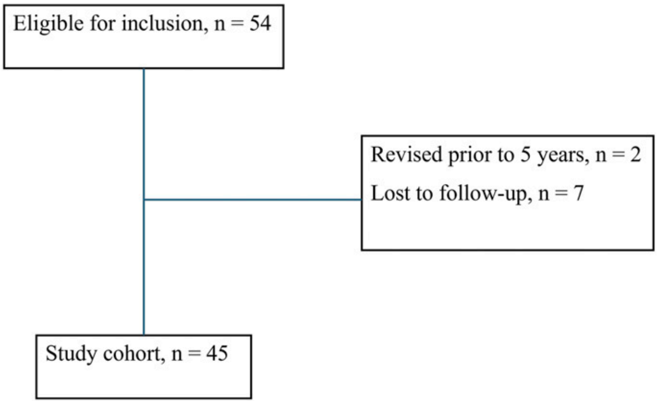

Fig. 2

CONSORT (Consolidated Standards of Reporting Trials) diagram of the study cohort.

female patients showed similar clinical results, albeit with female patients demonstrating slightly better abduction and internal rotation aROM than male patients (p = 0.019 and p = 0.014, respectively; Figs. 3 and 4, Table 2). One male patient reported dissatisfaction with his results at the final follow-up, but the remaining patients (97.8%) reported being either satisfied or very satisfied.

Two patients underwent revision for infection prior to the ≥5-year follow-up, resulting in a revision rate of 4.3% (2 of 47 patients) and a 7-year revision-free survival rate of 95.7% (Fig. 5). There were no other shoulder reoperations in the cohort. The 7-year failure-free survival rate was 93.4% (Fig. 5).

Radiographic Findings

Medialization

From the early postoperative period to 24 months, there was an average of 2.9 ± 2.8 mm (range, −2.5 to 10.4 mm) of medialization of the humeral head (p = 0.008). The majority (80%) of patients were categorized as having mild (>2 mm to ≤5 mm) to no medialization. The mean progression of medialization from 24-month imaging to final imaging was 1.1 mm, and the total mean amount of medialization at the time of final follow-up was 4.0 mm (Table 3). The change in medialization from the short-term to final follow-up was not significant (p = 0.096); however, the change from the early postoperative to final follow-up was significant (p < 0.001).

Of the 45 patients, 27 (60%) had no change in medialization category between the short-term and final radiographs, 12 (27%) progressed 1 category (2 from no medialization to minimal, 3 from minimal to mild, 5 from mild to moderate, 2 from moderate to severe), and 6 (13%) progressed 2 categories (3 from no medialization to mild, 2 from minimal to moderate, 1 from mild to severe) (p = 0.638; Table 3). One patient demonstrated severe medialization at 2 years; this number increased to 3 patients at the time of final follow-up, with a median medialization of 10.2 mm (range, 10.01 to 10.6 mm). All 3 patients were male (ages 37, 58, and 61 years) and had glenohumeral arthritis; 2 had type-A glenoids and 1 had a type-C glenoid, and each patient underwent glenoid shaping with a burr and/or microdrilling.

Of the 27 patients with no progression of medialization from 2 years postoperatively to the final follow-up, 3 continued to have no medialization and 4 had minimal, 13 had mild, 6 had moderate, and 1 had severe medialization. Of the 18 patients with progression of medialization, the mean medialization changed significantly (p < 0.001) from 2.0 ± 2.4 mm at 2 years to 5.4 ± 2.9 mm at the time of final follow-up (72.6 ± 9.0 months). In this group of patients, the rate of medialization was estimated to be 1.0 mm/year between the early postoperative period and 2 years and 0.85 mm/year between 2 and 6 years. In the multiple regression analysis incorporating all of the demographic factors of patients who demonstrated medialization, younger age was identified as the only significant predictor of severe medialization (p = 0.030). Given the numbers available, the outcomes in patients with progression of medialization by category were not significantly different from those in patients without progression of medialization (Table 4), with the exception of internal rotation aROM, which

Table 1. Study Cohort Demographics (N = 45)

Follow-up *(mo)*	
Mean ± SD	73 ± 8
Median (range)	70 (61-92)
Sex *(no. of patients)*	
Female	10 (22%)
Male	35 (78%)
Age at surgery *(yr)*	
Mean ± SD	52 ± 10
Median (range)	54 (19-69)
Smoking history *(no. of patients)*	
Current	3 (7%)
Former	10 (22%)
Never	32 (71%)
Shoulder *(no. of patients)*	
Left	17 (38%)
Right	28 (62%)
Primary diagnosis *(no. of patients)*	
Primary glenohumeral arthritis	40 (89%)
Posttraumatic osteonecrosis	2 (4.4%)
Atraumatic osteonecrosis	2 (4.4%)
Capsulorrhaphy arthropathy	1 (2%)
Prior surgery *(no. of patients)*	18 (40%)
Walch classification *(no. of patients)*	
A1	17 (38%)
A2	6 (13%)
B1	6 (13%)
B2	12 (27%)
C	2 (4.4%)
None	2 (4.4%)
Glenoid treatment *(no. of patients)*	
Shaping with burr with microfracture and/or drilling	27 (60%)
Microfracture and/or drilling	12 (26.7%)
Reaming	2 (4.4%)
None	4 (9%)

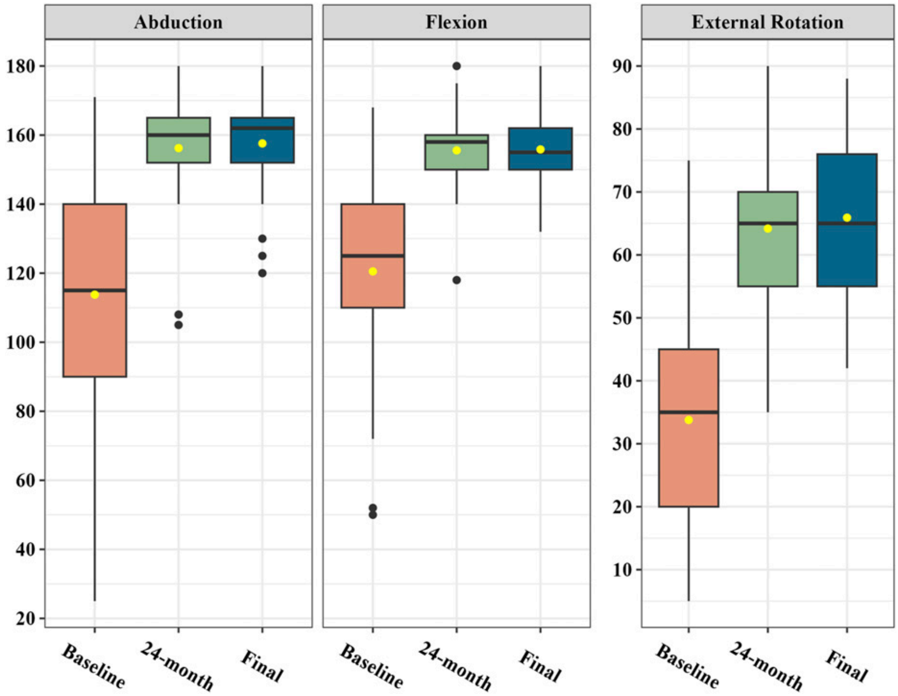

Fig. 3

Changes in active range of motion, in degrees. The horizontal line represents the median; the boundaries of the box represent the interquartile range (IQR); the whiskers represent the minimum and maximum values within 1.5 times the 1st or 3rd quartile; the black dots represent outliers, defined as points that fall outside 1.5 times the 1st or 3rd quartile; and the yellow dot represents the mean.

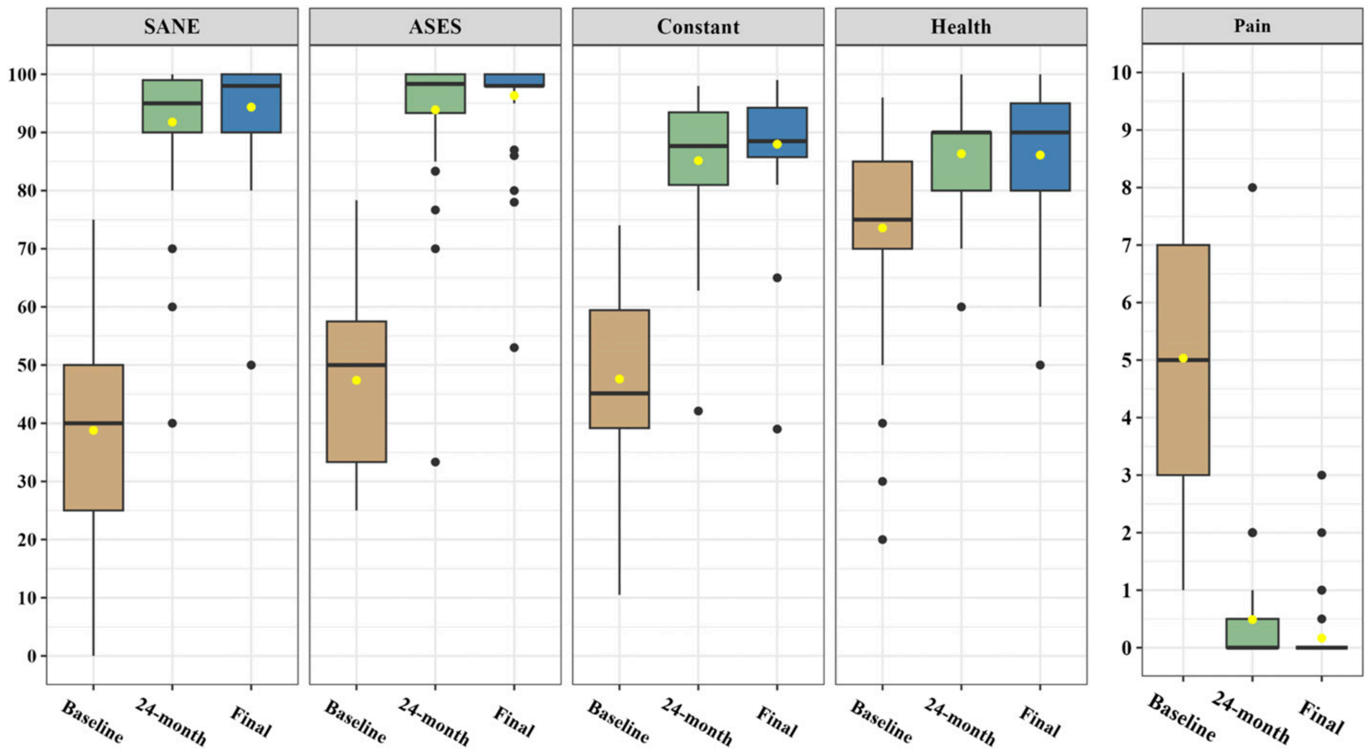

Fig. 4

Changes in PROMs. ASES = American Shoulder and Elbow Surgeons, SANE = Single Assessment Numeric Evaluation. The horizontal line represents the median; the boundaries of the box represent the interquartile range (IQR); the whiskers represent the minimum and maximum value within 1.5 times the 1st or 3rd quartile; the black dots represent outliers, defined as points that fall outside 1.5 times the 1st or 3rd quartile; and the yellow dot represents the mean.

Table 2. Change in Patient Outcomes from Baseline to 24 Months to the Final Follow-up (N = 45) and a Comparison of Outcomes at ≥5-Year Follow-up by Sex

	Baseline	24 Months	Final	P Value*	Female (N = 10)	Male (N = 35)	P Value
Flexion *(deg)*							
Mean ± SD	121 ± 26	156 ± 11	156 ± 9	<0.001	160 ± 10	155 ± 9	0.132
Median (range)	125 (50-168)	158 (118-180)	155 (132-180)		158 (143-180)	154 (132-178)	
Abduction *(deg)*							
Mean ± SD	114 ± 33	156 ± 14	158 ± 13	<0.001	166 ± 5	155 ± 14	0.019
Median (range)	115 (25-171)	160 (105-180)	162 (120-180)		165 (158-174)	160 (120-180)	
External rotation *(deg)*							
Mean ± SD	34 ± 18	64 ± 13	66 ± 12	<0.001	68 ± 15	65 ± 12	0.503
Median (range)	35 (5-75)	65 (35-90)	65 (42-88)		70 (45-88)	65 (42-85)	
Internal rotation *(no. of patients)*				<0.001			0.014
T7	2 (4.4%)	14 (31%)	12 (26.7%)		6 (60%)	6 (17%)	
T12	12 (26.7%)	23 (51%)	22 (48.9%)		4 (40%)	18 (51%)	
L5	9 (20%)	6 (13.3%)	11 (24.4%)		0 (0%)	11 (31%)	
Sacroiliac joint	8 (18%)	2 (4.4%)	0		0	0	
Buttock	11 (24.4%)	0	0		0	0	
Thigh	3 (6.7%)	0	0		0	0	
Satisfaction *(no. of patients)*				<0.001			>0.999
Very satisfied	0	39 (87%)	42 (93.3%)		10 (100%)	32 (91%)	
Satisfied	0	4 (8.9%)	2 (4.4%)		0 (0%)	2 (5.7%)	
Dissatisfied	17 (38%)	2 (4.4%)	1 (2.2%)		0 (0%)	1 (2.9%)	
Very dissatisfied	28 (62%)	0	0		0	0	
SANE score							
Mean ± SD	38.8 ± 20.0	91.8 ± 11.6	94.4 ± 8.8	<0.001	96.3 ± 4.0	93.8 ± 9.7	0.733
Median (range)	40 (0-75)	95 (40-100)	98 (50-100)		97 (90-100)	98 (50-100)	
Pain (0-10)							
Mean ± SD	5.0 ± 2.5	0.5 ± 1.3	0.2 ± 0.6	<0.001	0.0 ± 0.0	0.2 ± 0.6	0.220
Median (range)	5 (1-10)	0 (0-8)	0 (0-3)		0 (0-0)	0 (0-3)	
ASES score							
Mean ± SD	47.4 ± 15.3	93.9 ± 11.5	96.3 ± 8.3	<0.001	98.6 ± 1.3	95.7 ± 9.3	0.988
Median (range)	50 (25-78)	98 (33-100)	98 (53-100)		98 (97-100)	98.0 (53-100)	
Constant (raw) score (n = 44)							
Mean ± SD	47.6 ± 15.4	85.2 ± 11.3	88.0 ± 9.9	<0.001	85.1 ± 3.0	88.8 ± 11.0	0.005
Median (range)	45 (11-74)	88 (42-98)	89 (39-99)		86 (81-91)	91 (39-99)	
Health status (0%-100%) *(%)*							
Mean ± SD	73.6 ± 16.1	86.3 ± 7.9	86.1 ± 10.1	<0.001	87.0 ± 5.4	85.9 ± 11.1	0.802
Median (range)	75 (20-96)	90 (60-100)	90 (50-100)		90 (80-95)	90 (50-100)	

*Refers to the difference from baseline to final follow-up.

was slightly better in patients with progression by 2 categories (Table 5). A comparison of final medialization between patients with Walch type-A glenoids and those with type-B glenoids revealed no significant differences. In the 4 patients with osteonecrosis, joint space change was minimal, with a maximum decrease of 0.69 mm.

Additional Measures

The majority of patients demonstrated minimal changes in the CSA and β angle on final imaging (Fig. 1-D). The decrease in AHD from early postoperative imaging to final imaging was significant ($p < 0.001$; Fig. 1-C). Posterior subluxation in patients with Walch type-B glenoids decreased from 27.1% preoperatively to 19.8% postoperatively ($p = 0.008$).

Correlation of Radiographic Measures with Outcomes

Significant correlations included a low negative correlation between final β-angle change and final external rotation ($r = -0.40$; $p = 0.007$) and a low positive correlation between final joint space change and final abduction ($r = 0.37$; $p = 0.013$). None of the demographic variables predicted increased medialization in the multiple regression analysis.

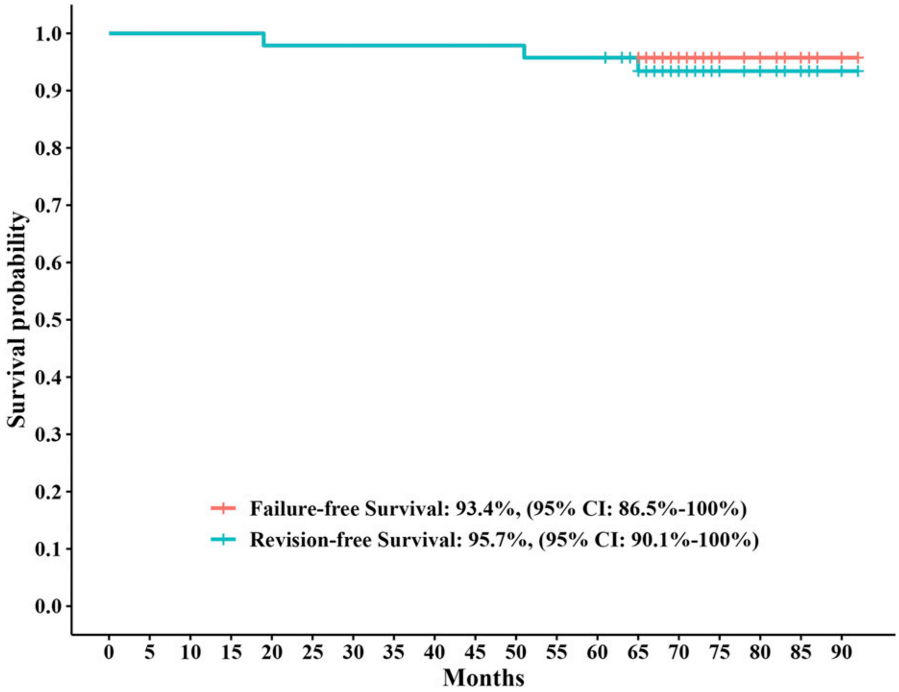

Fig. 5

Seven-year revision-free and failure-free survival. CI = confidence interval.

Discussion

This study evaluated glenohumeral joint changes, focusing on humeral head medialization from the 2-year to ≥5-year follow-up, and assessed the impact of these changes on the outcomes of patients who underwent PyC-HA. The overall mean medialization was 2.9 ± 2.8 mm at 2 years and progressed an additional 1.1 mm by the intermediate-term follow-up, resulting in a final mean medialization of 4.0 ± 3.3 mm at the ≥5-year follow-up. These results support the hypothesis of a minimal change in glenoid morphology from the short term to the intermediate term (Fig. 6). Significant improvements in all clinical outcomes and PROMs, as well as a 97.8% satisfaction rate, confirm the excellent outcomes at ≥5 years. In the multiple regression analysis incorporating all of the demographic factors of patients with progression of medialization, younger age was identified as the only significant predictor of severe medialization (p = 0.030). Additionally, there was no deterioration of PROMs in patients with progression of medialization by at least 1 category compared with those with no progression.

The potential for glenoid erosion is concerning when considering CoCr HA[18,22,23]. McBride et al. analyzed 393 various shoulder arthroplasty procedures in young patients (<55 years old)[24]. Forty percent of patients underwent PyC hemi-resurfacing, while 60% underwent either CoCr hemi-resurfacing or CoCr stemmed HA. At 6 years, 8.9% of PyC cases and 17% of metal cases required revision, although the difference was not significant. Glenoid erosion was the primary reason for revision in CoCr hemi-resurfacing (32.5%) and CoCr stemmed HA (46.7%). In contrast, PyC hemi-resurfacing revisions were primarily due to implant breakage (57.1%) and pain (28.6%), with no cases of revision for

Table 3. Progression of Humeral Head Medialization from the 2-Year to Final Follow-up

	2 Years (N = 45)	5-7 Years (N = 45)	P Value
Medialization *(mm)*			0.096
Mean ± SD	2.9 ± 2.8	4.0 ± 3.3	
Median (range)	2.9 (−2.5 to 10.4)	3.4 (−2.5 to 10.6)	
Medialization category *(no. of patients)*			0.638
Severe (>10 mm)	1 (2.2%)	3 (6.7%)	
Moderate (>5 to ≤10 mm)	8 (17.8%)	12 (26.7%)	
Mild (>2 to ≤5 mm)	19 (42.2%)	17 (38%)	
Minimal (>0 to ≤2 mm)	9 (20%)	8 (17.8%)	
No medialization	8 (17.8%)	5 (11%)	

Table 4. Comparison of Final Outcomes Between Patients with and without Progression of Medialization by ≥1 Category

	No Progression (N = 27)	Progression (N = 18)	P Value
Flexion *(deg)*			0.880
Mean ± SD	156 ± 10	156 ± 8	
Median (range)	156 (132-180)	154 (145-178)	
Abduction *(deg)*			0.335
Mean ± SD	155 ± 15	161 ± 9	
Median (range)	160 (120-180)	162 (140-174)	
External rotation *(deg)*			0.659
Mean ± SD	65 ± 13	67 ± 12	
Median (range)	68 (42-85)	65 (48-88)	
Internal rotation *(no. of patients)*			0.535
T7	6 (22%)	6 (33%)	
T12	15 (56%)	7 (39%)	
L5	6 (22%)	5 (28%)	
Satisfaction *(no. of patients)*			0.999
Very satisfied	25 (93%)	17 (94%)	
Satisfied	1 (3.7%)	1 (5.6%)	
Dissatisfied	1 (3.7%)	0 (0%)	
SANE score			0.261
Mean ± SD	93.0 ± 10.4	96.4 ± 5.3	
Median (range)	95 (50-100)	99 (80-100)	
Pain (0-10)			0.983
Mean ± SD	0.2 ± 0.6	0.1 ± 0.5	
Median (range)	0 (0-3)	0 (0-2)	
ASES score			0.112
Mean ± SD	95.6 ± 9.6	97.4 ± 5.9	
Median (range)	98 (53-100)	100 (78-100)	
Constant (raw) score*			0.227
Mean ± SD	86.8 ± 11.2	89.7 ± 7.5	
Median (range)	87 (39-98)	90 (65-99)	
Health status (0%-100%) *(%)*			0.887
Mean ± SD	85.7 ± 10.9	86.7 ± 8.8	
Median (range)	90 (50-99)	90 (75-100)	

*N = 26 in the No Progression group.

glenoid erosion[24]. Similarly, the findings of the present study suggest that the solid PyC implant utilized in this study may be useful for shoulder hemiarthroplasty: the 2 revisions in this cohort were infection-related, and there were no reoperations for stiffness or revisions due to glenoid erosion or implant breakage.

Garret et al. evaluated radiographic and clinical outcomes in 45 patients undergoing PyC-HA, with follow-up visits at 2.2 and 6.2 years[25]. At 2.2 years, 92% of patients reported being satisfied, with 16% demonstrating progression of glenoid erosion. In the intermediate term, 90% remained satisfied, with 14% showing further erosion. Overall, 27% of patients had erosion progression of 1 to 2 grades, with moderate erosion in 24% and severe erosion in 8.1% of patients by the final follow-up[25]. The findings of the present study are similar in that severe erosion (>10 mm) was observed in only 3 patients at a mean of 73 months postoperatively, and 60% of patients did not progress by at least 1 erosion grade between the short and intermediate term. A consequential difference between these studies is that the medialization categories described in the present study are based on quantitative measurements (Fig. 1-B) rather than the Sperling classification method, which subjectively classifies glenoid erosion as none, mild, moderate, or severe on the basis of the observed glenoid morphology[22].

Quantifying the extent of medialization requires an objective method of measurement. Kleim et al. conducted a study of PyC-HA using magnification-controlled radiographic techniques to precisely measure humeral head medialization[26]. They reported 1.4 mm of medialization over 5.5 years, with more medialization occurring in the first year (0.8 mm) compared with subsequent years (0.3 mm). Patients who

Table 5. Comparison of Final Outcomes by Medialization Category Progression

	No Progression (N = 27)	Progressed 1 Category (N = 12)	Progressed 2 Categories (N = 6)	P Value
Flexion *(deg)*				0.968
Mean ± SD	156 ± 10	156 ± 6	157 ± 12	
Median (range)	156 (132-180)	154 (148-170)	155 (145-178)	
Abduction *(deg)*				0.515
Mean ± SD	155 ± 15	162 ± 8	158 ± 11	
Median (range)	160 (120-180)	162 (150-174)	162 (140-170)	
External rotation *(deg)*				0.684
Mean ± SD	65 ± 13	69 ± 11	64 ± 14	
Median (range)	68 (42-85)	68 (50-84)	63 (48-88)	
Internal rotation *(no. of patients)*				0.019
T7	6 (22%)	1 (8.3%)	5 (83%)	
T12	15 (56%)	6 (50%)	1 (17%)	
L5	6 (22%)	5 (42%)	0 (0%)	
Satisfaction *(no. of patients)*				0.794
Very satisfied	25 (93%)	11 (92%)	6 (100%)	
Satisfied	1 (3.7%)	1 (8.3%)	0 (0%)	
Dissatisfied	1 (3.7%)	0 (0%)	0 (0%)	
SANE score				0.506
Mean ± SD	93.0 ± 10.4	95.7 ± 6.2	97.8 ± 2.3	
Median (range)	95 (50-100)	99 (80-100)	99 (95-100)	
Pain (0-10)				0.920
Mean ± SD	0.2 ± 0.6	0.2 ± 0.6	0.1 ± 0.2	
Median (range)	0 (0-3)	0 (0-2)	0 (0-0)	
ASES score				0.275
Mean ± SD	95.6 ± 9.6	97.5 ± 6.2	97.3 ± 5.6	
Median (range)	98 (53-100)	100 (78-100)	100 (86-100)	
Constant (raw) score*				0.295
Mean ± SD	86.8 ± 11.2	90.2 ± 9.0	88.7 ± 3.4	
Median (range)	87 (39-98)	93 (65-99)	88 (86-95)	
Health status (0%-100%) *(%)*				0.859
Mean ± SD	85.7 ± 10.9	85.8 ± 8.9	88.3 ± 9.3	
Median (range)	90 (50-99)	87 (75-100)	90 (75-100)	

*N = 26 in the No Progression group.

underwent glenoid reaming had slightly more medialization (0.4 mm) than those who did not (0.2 mm), although the difference was not significant (p = 0.09). However, the study's limited follow-up data, with fewer patients at each time point[26], represents a limitation compared with the present study, which measured humeral head medialization in all study subjects at ≥5 years of follow-up. As might be expected with more complete follow-up, the amount of medialization observed at final imaging in the full cohort of the present study was greater than that reported by Kleim et al.[26]; however, the present study also demonstrated that the greatest amount of medialization in most patients occurred within the first 2 years. A recent study by Ranieri et al. quantified glenoid erosion at a shorter minimum follow-up (2 years) using 2D computed tomography (CT) scans of type-B glenoids treated with PyC-HA and concentric reaming[27]. Ranieri et al. measured 3.7 mm of medialization at a mean follow-up of 4.5 years (range, 2 to 9.5 years). They attributed 2.0 mm to reaming and 1.7 mm to erosion. The patient outcomes were consistent with those in the present study[27].

The authors agree with Matsen et al. that rebalancing glenohumeral anatomy may require surgical recentering of the humeral head on the glenoid[10]. One effective technique to achieve this is concentric reaming of the glenoid (i.e., "ream and run" [RnR]), which employs conservative reaming to recreate a concave glenoid surface, maximizing the glenohumeral contact area for load transfer. A comprehensive review of RnR with CoCr stemmed HA[10] revealed good outcomes at intermediate[11,12,28-32] and long-term follow-up[13] but also described cases of early postoperative stiffness, with rates of manipulation under anesthesia ranging from 2% to 14%[11-13,28-30]; postoperative pain; and rates of conversion to anatomical arthroplasty ranging

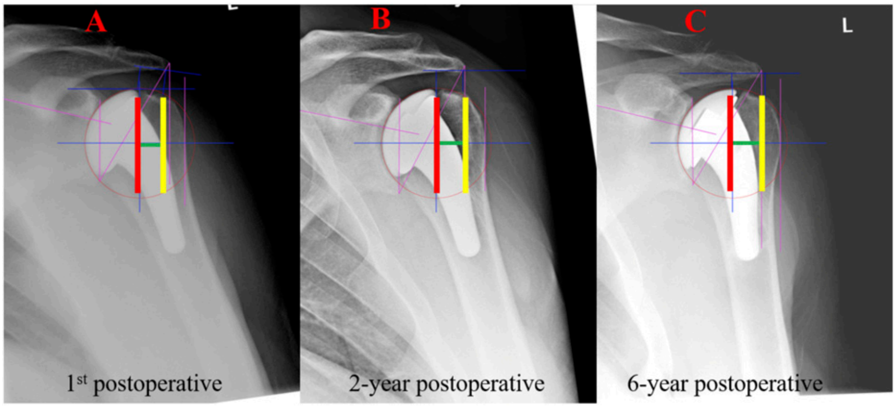

Fig. 6

Fig. 6-A: Immediate postoperative radiograph of a patient after PyC-HA with biological glenoidplasty. The center of rotation of the humeral head is indicated by the vertical red line, the lateral edge of the acromion is indicated by the vertical yellow line, and the difference between the 2 lines indicates the amount of medialization (green line). **Fig. 6-B:** Two-year postoperative radiograph demonstrating minimal medialization (0.6 mm). **Fig. 6-C:** Six-year postoperative radiograph demonstrating minimal medialization at mid-term follow-up (0.5 mm).

from 3% to 18%[11-13,28,30-32]. In the present study, 27 patients (60%) underwent glenoidplasty, which is a subtle modification of RnR in which a handheld burr is used to create a monoconcave glenoid in the axial and coronal planes, recentering the humeral head on the glenoid while minimizing bone removal and preserving the intact labrum. Minimal glenoid treatment was

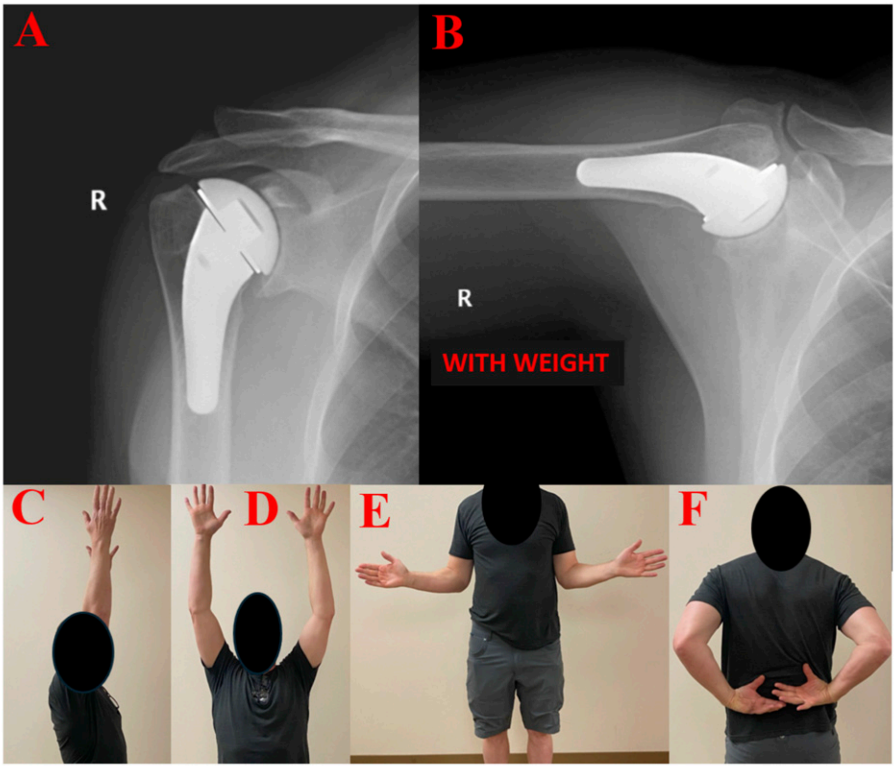

Fig. 7

Figs. 7-A and 7-B: Radiographs and clinical pictures of a patient 7 years after PyC-HA. **Fig. 7-A:** Anteroposterior radiograph demonstrating slight superior humeral migration 7 years after PyC-HA. **Fig. 7-B:** Weight-bearing anteroposterior radiograph demonstrating recentering of the humeral head on the glenoid at 7 years postoperatively. The weight-bearing view was made with the patient in a standing position and rotated 35° to 45° toward the affected shoulder to align the scapula parallel to the imaging receptor, ensuring a true-AP radiograph of the glenohumeral joint. With the arm in neutral rotation, the patient held a 2-lb (1-kg) weight at approximately 70° of shoulder abduction. If the patient was unable to tolerate 2 lb, the weight of the arm was utilized and the images were marked as "no weight." **Figs. 7-C through 7-F:** Photographs of 7-year postoperative clinical outcomes, demonstrating excellent postoperative range of motion.

performed in shoulders with intact glenoid cartilage and a centered glenohumeral joint or in those with type-A glenoids. These bone-preserving techniques, in addition to the PyC bearing, may have contributed to the clinical outcomes and improvement of centering observed in patients with Walch type-B glenoids in this study.

The changes in CSA and β angle were not significant, with the majority of patients categorized as having minimal change from the early postoperative to final follow-up. This indicates that there was no predilection for eccentric superior glenoid erosion in these patients, despite the significant decrease in AHD from the early postoperative imaging to the final imaging ($p < 0.001$). The authors have found that, in these cases, an active weighted abduction radiograph more accurately demonstrates centering of the humeral head on the glenoid in the coronal plane, indicating a properly functioning rotator cuff (Fig. 7).

This study represents a large cohort of patients with intermediate-term outcomes who were managed with PyC-HA and consistent glenoid treatment, but it does have limitations. Although the radiographic measurements were obtained using an objective, reproducible method, the lack of fluoroscopic or CT control of the images introduced the potential for measurement error. The relative consistency of glenoid treatment can also be considered a weakness, as this uniformity did not allow for a thorough analysis of how differing glenoid treatments might affect glenohumeral recentering, medialization, and the associated outcomes. Another limitation of this study was the inability to accurately measure the amount of medialization occurring iatrogenically at the time of surgery during preparation of the glenoid. Additionally, the absence of race and/or ethnicity data introduces a limitation that may impact the generalizability of this study. Finally, 5 to 7-year outcomes should be considered only intermediate-term outcomes in shoulder arthroplasty. Larger cohort-controlled and prospective randomized studies comparing PyC-HA to other arthroplasty options with differing glenoid treatments and longer-term follow-up are required.

Conclusions

This study demonstrated that PyC-HA is a reliable treatment method for patients with glenohumeral arthritis, providing excellent improvement in PROMs while demonstrating an acceptable rate of humeral head medialization and a high rate of implant survival at intermediate-term follow-up. ■

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