J Shoulder Elbow Surg (2023) ■, 1–7

ELSEVIER

Journal of Shoulder and Elbow Surgery

www.elsevier.com/locate/ymse

Short-term outcomes following 159 stemmed pyrolytic carbon shoulder hemiarthroplasties and how they compare with conventional hemiarthroplasties and total shoulder arthroplasties in patients younger than 60 years with osteoarthritis: results from the New Zealand National Joint Registry

Ryan Gao, MBChB, PhD, FRACS[a,*], Aparna Viswanath, FRCS(Tr&Orth)[b], Chris M. Frampton, BSc(Hons), PhD[c], Peter C. Poon, MBChB, FRACS[a]

[a]*Department of Orthopaedic Surgery, Northshore Hospital, Auckland, New Zealand*
[b]*James Cook University Hospital, Middlesbrough, UK*
[c]*Department of Medicine, University of Otago, Christchurch, New Zealand*

Background: Despite the increasing use of pyrolytic carbon (pyrocarbon) hemiarthroplasty (PyCHA), clinical data reporting on its outcomes remain scarce. To date, no studies have compared the outcomes of stemmed PyCHA vs. conventional hemiarthroplasty (HA) and anatomic total shoulder arthroplasty (aTSA) in young patients. The primary aim of this study was to report on the outcomes of the first 159 stemmed PyCHAs performed in New Zealand. The secondary aim was to compare the outcomes of stemmed PyCHA vs. HA and aTSA in patients aged <60 years with osteoarthritis. We hypothesized that stemmed PyCHA would be associated with a low revision rate. We further hypothesized that in young patients, PyCHA would be associated with a lower revision rate and superior functional outcomes compared with HA and aTSA.

Methods: Data from the New Zealand National Joint Registry were used to identify patients who underwent PyCHA, HA, and aTSA between January 2000 and July 2022. The total number of revisions in the PyCHA group was determined, and the indications for surgery, reasons for revision, and types of revision were recorded. In patients aged <60 years, a matched-cohort analysis was performed comparing functional outcomes using the Oxford Shoulder Score (OSS). The revision rate of PyCHA was compared with that of HA and aTSA, calculated as revisions per 100 component-years.

Results: In total, 159 cases of stemmed PyCHA were performed and 5 cases underwent revision, resulting in an implant retention rate of 97%. Among patients aged <60 years with shoulder osteoarthritis, 48 underwent PyCHA compared with 150 who underwent HA and 550 who underwent aTSA. Patients treated with aTSA had a superior OSS compared with PyCHA and HA patients. The difference in

Institutional Review Board approval was received from the New Zealand National Joint Registry. The local institutional ethics committee provided approval for hospital data collection when this joint registry was established. We received fully anonymized data, with no patient identifiers and no surgeon identifiers.

*Reprint requests: Ryan Gao, MBChB, PhD, FRACS, Department of Orthopaedic Surgery, Northshore Hospital, Auckland, New Zealand.
E-mail address: ygao921@gmail.com (R. Gao).

https://doi.org/10.1016/j.jse.2023.01.020

the OSS between the aTSA and PyCHA groups exceeded the minimal clinically important difference of 4.3. There was no difference in revision rates between the groups.

Conclusions: This study represents the largest cohort of patients treated with PyCHA and is the first to compare stemmed PyCHA with HA and aTSA in young patients. In the short term, PyCHA appear to be a promising implant with an excellent implant retention rate. In patients aged <60 years, the revision rate is comparable between PyCHA and aTSA. However, aTSA remains the implant of choice to optimize early postoperative function. Further studies are required to elucidate the long-term outcomes of PyCHA, particularly how they compare with those of HA and aTSA in young patients.

Level of evidence: Level III; Retrospective Cohort Comparison Using Large Database; Treatment Study

Keywords: Pyrocarbon; pyrolytic carbon; hemiarthroplasty; osteoarthritis; anatomic shoulder arthroplasty; total shoulder arthroplasty

The management of young patients with end-stage shoulder osteoarthritis remains a clinical challenge owing to the paucity of high-level evidence to guide treatment.[3,7,8,25] Arthroplasty options addressing young patients with shoulder osteoarthritis include anatomic total shoulder arthroplasty (aTSA) and hemiarthroplasty (HA) with conventional metallic heads, each with its inherent risks and complication profile. Although aTSA offers excellent predictable results in the short term, accelerated glenoid component wear and failure often lead to unacceptable outcomes in young patients.[3,7,14,29] Furthermore, revision surgery after aTSA can be technically challenging owing to catastrophic glenoid bone loss and destruction.[2,4,9,18,19] To avoid polyethylene glenoid prosthesis wear and loosening, HA is an alternative option. Unfortunately, HAs with conventional metallic heads resulted in unacceptably high revision rates in multiple studies owing to the unfavorable articulation of conventional metallic alloys with the native glenoid.[3,8,27,29] The undesirable effect of conventional metal on the native glenoid articulation has led to the development of pyrolytic carbon (pyrocarbon) as an alternative bearing surface for shoulder HA.[5,20]

Pyrocarbon has a Young's modulus of elasticity close to that of cortical bone, a low coefficient of friction, and excellent fatigue resistance properties.[5,15] In orthopedic surgery, pyrocarbon has been successfully used for interposition arthroplasty in the small joints of the hand and as a bearing surface for joint replacement in the elbow.[24,28] In the shoulder joint, an in vitro study under simulated physiological conditions showed that pyrocarbon humeral head prostheses produced significantly less erosive wear damage to bone than a conventional cobalt chrome prosthesis.[16] In vivo, clinical studies reporting on the outcomes of pyrocarbon shoulder HA remain scarce. Two recent studies reported favorable short- to medium-term outcomes of pyrocarbon humeral HA for the treatment of young patients with shoulder osteoarthritis.[5,20] Unfortunately, neither study compared the outcomes of pyrocarbon hemiarthroplasty (PyCHA) vs. aTSA. Therefore, the clinical quandary of whether young patients with end-stage osteoarthritis of the shoulder should be treated with PyCHA or aTSA remains.

The primary aim of our study was to report on the short-term outcomes of the first 159 stemmed PyCHAs performed in New Zealand. Our secondary aim was to compare the short-term outcomes of PyCHA vs. HA and aTSA in patients aged <60 years with primary shoulder osteoarthritis. We hypothesized that the stemmed PyCHA would be associated with a low revision rate overall. We further hypothesized that in young patients (aged <60 years) with shoulder osteoarthritis, PyCHA would be associated with a lower revision rate and superior functional outcomes compared with HA and aTSA.

Materials and methods

New Zealand National Joint Registry

The New Zealand National Joint Registry was established in 1999 and began collecting data on shoulder arthroplasties on January 1, 2000. Data are collected from patients throughout New Zealand, with the compliance rate exceeding 95%.[10] Participation by surgeons is compulsory for annual accreditation by the New Zealand Orthopaedic Association. The New Zealand National Joint Registry produces annual reports that are publicly available. The rate of implant survival to revision is summarized as revisions per 100 component-years. This summary allows comparison of components that have been implanted for differing lengths of time. A value of 1 revision per 100 component-years corresponds to revision rates of 1% at 1 year and 10% at 10 years. The rate of revision per 100 component-years is calculated as follows: Revisions per 100 component-years = Number of revisions × 100/component-years, in which component-years is defined as total years of follow-up for all surgical procedures and follow-up for an individual case is defined as the time from surgery to revision or death. In patients undergoing shoulder arthroplasty, the self-assessed Oxford Shoulder Score (OSS)[6] is used as the patient-reported outcome measure, with patients completing the OSS questionnaire at 6 months and 5 years after surgery. Patient diagnoses are collected based on surgeons adjudicating a single primary diagnosis and ticking one of the designated options on the joint registry data form.

Patients

Data covering the period between January 2000 and July 2022 were obtained from the New Zealand National Joint Registry. Diagnoses in patients undergoing shoulder arthroplasty included

Table I Sex and age distributions according to implant type

Group	N	Male sex, %	Age, yr			
			Mean	Minimum	Maximum	SD
PyCHA	159	66	53.0	20	86	11.2
HA	1280	40	65.2	15	86	13.1
aTSA	4285	40	67.6	23	86	8.9

SD, standard deviation; *PyCHA*, pyrolytic carbon hemiarthroplasty; *HA*, hemiarthroplasty with conventional metallic heads; *aTSA*, anatomic total shoulder arthroplasty.

Table II Indications for surgery according to implant type

Indication	PyCHA	HA	aTSA
Osteoarthritis	76 (47.8)	727 (56.9)	3730 (87)
AVN	33 (20.8)	103 (8)	98 (2.3)
Prior trauma	27 (17)	177 (13.8)	135 (3.2)
RA	5 (3.1)	209 (16.3)	264 (6.2)
Other	18 (11.3)	64 (5)	58 (1.3)
Total	159 (100)	1280 (100)	4285 (100)

PyCHA, pyrolytic carbon hemiarthroplasty; *HA*, hemiarthroplasty with conventional metallic heads; *aTSA*, anatomic total shoulder arthroplasty; *AVN*, avascular necrosis; *RA*, rheumatoid arthritis.
Data are presented as number (percentage).

primary osteoarthritis, rheumatoid arthritis, prior trauma, other inflammatory condition, dislocation, and avascular necrosis. The patients included in this study were those who underwent either a stemmed PyCHA, a conventional shoulder HA with metallic heads, or an aTSA via any implant system. Patients who underwent arthroplasty for acute trauma or rotator cuff tears were excluded from this study. Furthermore, despite the presence of 2 types of pyrocarbon humeral implant in the New Zealand National Joint Registry—the PyroTitan implant (Integra, Princeton, NJ, USA) and the pyrocarbon humeral head on the Tornier Flex stem (Tornier SAS [Stryker], Montbonnot-Saint-Martin, France)—the PyroTITAN cases were excluded from our analysis. We excluded the pyrocarbon humeral resurfacing implant from this study because the PyroTitan implant was voluntarily withdrawn from the market in New Zealand because of reports of implant breakage.[1,20,23]

Statistical analysis

The revision rates are summarized as the revision rates per 100 component-years, and the temporal pattern of revisions is presented as a Kaplan-Meier curve. The presenting features were compared between the groups using the χ^2 test or 1-way analysis of variance as appropriate. A 2-tailed $P < .05$ is considered statistically significant. For 6-month OSS, our study had >90% power to detect a 3.0-point difference between the PyCHA group and either of the 2 comparison groups. For the revision rates, our study had approximately 80% power to detect a doubling (or worse) in revision rate between the PyCHA group and the HA or aTSA group.

Results

Short-term outcomes of 159 patients treated with stemmed PyCHA

During the study period, a total of 159 stemmed PyCHA procedures were performed compared with 1280 HAs and 4285 aTSAs. The stemmed PyCHA implants used in this study were universally the pyrocarbon humeral head on the Tornier Flex stem. The mean follow-up duration in the PyCHA, HA, and aTSA groups was 3.3 years (range, 0.03-7.7 years), 12.7 years (range, 0.06-21.9 years), and 8.3 years (range, 0.02-21.9 years), respectively.

Patient demographic characteristics

The mean age of the patients in the PyCHA group was 53 years (standard deviation [SD], 11.2 years), with a minimum age of 20 years and maximum age of 86 years. The mean age in the PyCHA group was significantly lower than that in the other 2 groups, with mean ages of 65.2 years (SD, 13.1 years) and 67.6 years (SD, 8.9 years) in the HA and aTSA groups, respectively ($P < .01$) (Table I). A difference in the sex distribution was observed between the PyCHA group and the HA and aTSA groups. In the PyCHA group, 66% of patients were men compared with 40% in both the HA and aTSA groups.

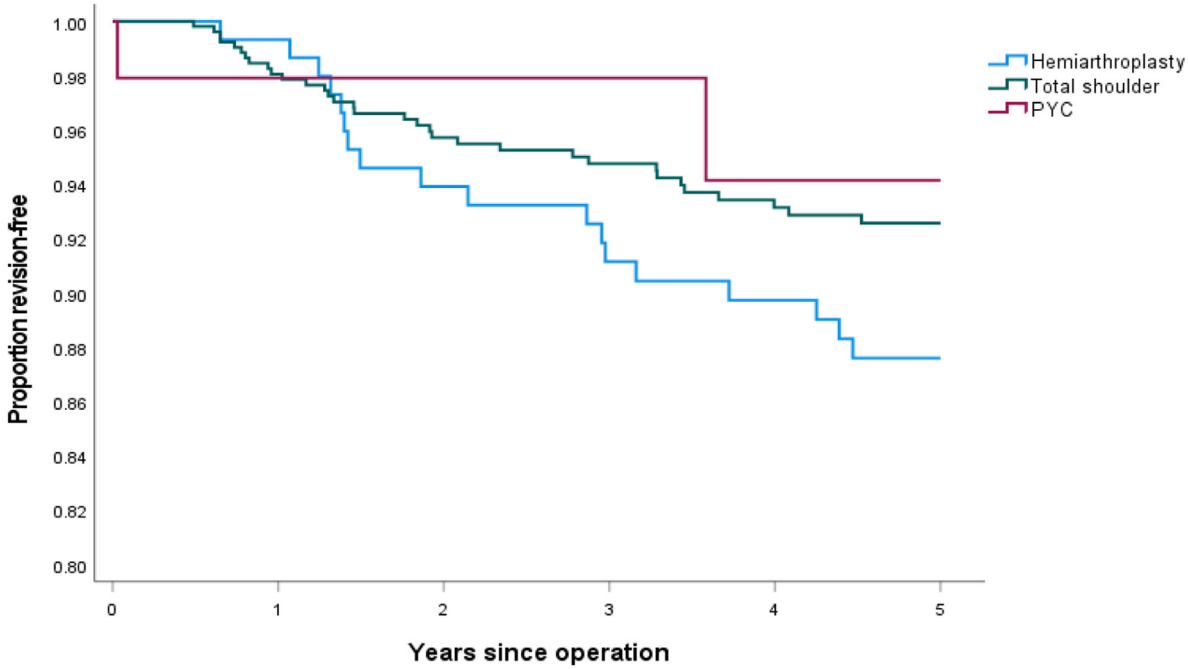

Figure 1 Kaplan-Meier curve showing revision rates over time for patients aged <60 years with shoulder osteoarthritis treated with pyrolytic carbon hemiarthroplasty *(PYC)*, hemiarthroplasty with conventional metallic heads, and anatomic total shoulder arthroplasty.

Indications for surgery

The underlying diagnoses were different between the 3 groups of patients (Table II). In the PyCHA group, the top 3 indications for surgery were osteoarthritis (n = 76, 47.8%), avascular necrosis (n = 33, 20.8%), and prior trauma (n = 27, 17%). The top 3 primary indications in the HA and aTSA groups were osteoarthritis, rheumatoid arthritis, and prior trauma.

Revisions in PyCHA group

In total, 5 revisions were performed in the PyCHA group, with patients ranging in age from 37 to 66 years. The indications for the index surgical procedure were osteoarthritis (n = 3), prior trauma (n = 1), and dislocation (n = 1). The time from index surgery to revision ranged from 0.03 to 3.58 years. Three patients underwent revision owing to "overstuffing" of the glenohumeral joint due to oversized implants, and the other 2 patients underwent revision owing to rotator cuff failure. In the 3 patients who underwent revision for overstuffing of the glenohumeral joint, the humeral components were revised to smaller implants. The remaining 2 patients with revision for rotator cuff failure underwent revision to reverse shoulder arthroplasty.

Revisions in young patients with osteoarthritis

Of the patients aged <60 years with osteoarthritis, 48 underwent PyCHA, 150 underwent HA, and 550 underwent aTSA. Two patients in the PyCHA group underwent revision during the study period. The first was a 37-year-old man who underwent revision to a smaller pyrocarbon head component after 3 months because of joint overstuffing. The second was a 46-year-old man who underwent revision to reverse shoulder arthroplasty after 43 months due to rotator cuff failure. The Kaplan-Meier curve showing revision rates over time is presented in Figure 1. The revision rate (calculated as rate per 100 component-years) in patients aged <60 years with osteoarthritis was 1.275, 2.654, and 1.613 for PyCHA, HA, and aTSA, respectively. Although there was a trend toward a lower revision rate in the PyCHA group compared with the HA and aTSA groups, the differences did not reach the level of statistical significance ($P > .05$).

Functional outcomes in young patients with osteoarthritis

In patients aged <60 years with osteoarthritis, the functional outcomes were reported using the OSS with matching for age and sex (Table III). The 6-month postoperative OSS was 33.0, 33.5, and 37.6 in the PyCHA group, HA group, and aTSA group, respectively. The differences in the total OSS and the pain and function subcategory scores were statistically significant between the aTSA and PyCHA groups ($P < .05$) but were not statistically significant between the PyCHA and HA groups ($P > .05$). Although the New Zealand National Joint Registry also collects the OSS at 5 years postoperatively, the 5-year OSS was only

Table III OSS at 6 months in patients aged <60 years with shoulder osteoarthritis according to implant type

	n	OSS at 6 mo			*P* value (compared with PyCHA group)
		Mean	95% CI		
			Lower limit	Upper limit	
Total					
PyCHA group	19	33.0	29.2	36.7	NA
HA group	79	33.5	31.6	35.4	.81
aTSA group	284	37.6	36.6	38.7	.02*
Pain					
PyCHA group	19	8.5	6.8	10.1	NA
HA group	79	8.6	7.8	9.4	.87
aTSA group	284	10.3	9.9	10.7	.03*
Function					
PyCHA group	19	24.5	22.1	27.0	NA
HA group	79	24.9	23.7	26.1	.79
aTSA group	284	27.4	26.7	28	.03*

OSS, Oxford Shoulder Score; *CI*, confidence interval; *PyCHA*, pyrolytic carbon hemiarthroplasty; *NA*, not applicable; *HA*, hemiarthroplasty with conventional metallic heads; *aTSA*, anatomic total shoulder arthroplasty.
* Statistically significant difference.

available for 3 patients who underwent PyCHA. Therefore, no meaningful comparison between the groups was possible at this later time point.

Discussion

Pyrocarbon has tribological qualities and elastic properties close to those of cortical bone, and pyrocarbon implants have been successfully used in wrist and elbow surgery.[11,13,15,21,26] However, clinical reports following the use of pyrocarbon in the shoulder joint have been scarce. To our knowledge, this study represents the largest cohort of patients treated with stemmed PyCHA. Furthermore, this is the first study to directly compare the outcomes of stemmed PyCHA vs. HA and aTSA in patients aged <60 years with shoulder osteoarthritis.

The findings of this study support our first hypothesis and confirm that PyCHA is associated with an excellent implant retention rate in the short term. Among a total of 159 PyCHAs performed during the study period, 5 required revision. The high implant retention rate (97%) is in keeping with the findings of other studies in the literature. Garret et al[11] reported a 95% implant survival rate at 2 years in a cohort of 61 patients who underwent stemmed PyCHA. In another study, with 64 consecutive patients treated with stemmed PyCHA, the implant survival rate at 3 years was 92%.[5]

In this series of patients, 3 of 5 cases underwent revision for overstuffing of the joint, which is a recognized complication following stemmed PyCHA. In a series of 64 patients treated with stemmed PyCHA, Cointat et al[5] showed that the stemmed PyCHA prosthesis was oversized and/or too proud in one-third of the patients. The nonanatomic humeral reconstruction caused joint overstuffing and resulted in inferior functional outcomes and a higher revision rate owing to rotator cuff failure and early glenoid erosion.[5] The reason for the high rate of nonanatomic humeral reconstruction in the earlier cases was the learning curve associated with this novel implant design. The pyrocarbon heads on the Tornier Flex stem are approximately 2 mm thicker than the metallic heads for the same diameter. The increased thickness results from an additional 1.5-mm metallic tray to support the pyrocarbon head to prevent breakage of the pyrocarbon head. In addition, there is a 0.5-mm void under the metallic plate to accommodate the Morse taper.[5] The added thickness must be taken into account when the pyrocarbon head is used on the Tornier Flex stem. Surgeons are encouraged to downsize the pyrocarbon head by at least 1 size to prevent joint overstuffing.

The secondary aim of this study was to compare the outcomes of stemmed PyCHA vs. HA and aTSA in young patients with shoulder osteoarthritis. We considered young patients to be aged <60 years. Our hypothesis of a lower revision rate and superior OSS in the PyCHA group compared with the HA and aTSA groups was not supported. Although the superior results of aTSA over HA are well reported in the literature,[3,12,17] this study is the first to directly compare the results of PyCHA vs. HA and aTSA in young patients with shoulder osteoarthritis. Among the patients aged <60 years, 48 underwent PyCHA compared with 150 who underwent HA and 550 who underwent aTSA during the study period. Although there was a trend toward a lower revision rate in the PyCHA group compared with the HA and aTSA groups, the differences did not reach

the level of statistical significance ($P > .05$). Further studies with longer-term follow-up are warranted to elucidate the implant survival rates and how they compare between the 3 groups. In terms of functional outcomes at 6 months, the aTSA group had the highest OSS (37.6) in patients aged <60 years compared with the PyCHA group (33.0) and HA group (33.5) when the data were matched for sex and age. The difference in the mean OSS between the PyCHA and aTSA groups (4.6) exceeded the minimal clinically important difference of 4.3 as reported by Nyring et al.[22] The reasons for the inferior OSS in the PyCHA group compared with the aTSA group are likely multifactorial and warrant further investigation. One potential reason for the discrepancy in the postoperative functional outcomes is that the patients in the PyCHA group had more advanced arthritis and worse shoulder pathologies than the patients in the HA and aTSA groups. Unfortunately, no preoperative patient-reported outcome scores were recorded by the New Zealand National Joint Registry. The lack of preoperative functional scores limits the ability to interpret any procedure-related improvement in functional status. It is plausible that the patients who underwent PyCHA may have had inferior OSS values compared with the HA and aTSA groups preoperatively and that the improvement in function after PyCHA may potentially be greater than in the other 2 groups.

Limitations

This study has several limitations. First, the OSS used to assess postoperative function was subjective, and objective clinical and radiographic data were not available owing to the retrospective nature of this study. Second, our study only reported on early functional outcomes using the OSS at 6 months. The limited data available at longer-term follow-up are partially explained by the relative novelty of the PyCHA implant. Further follow-up studies are required to elucidate the long-term outcomes of patients treated with PyCHA and how they compare with those of patients treated with HA and aTSA.

Conclusion

To our knowledge, this study represents the largest cohort of patients treated with stemmed PyCHA and is the first to compare the outcomes of stemmed PyCHA vs. HA and aTSA in patients aged <60 years with shoulder osteoarthritis. The findings of this study showed that PyCHA is a promising implant with a good implant retention rate in the short term. In patients aged <60 years, PyCHA demonstrated a comparable implant retention rate to aTSA. However, in the short term, aTSA remains the implant of choice to optimize early postoperative function. Further studies are required to elucidate the long-term outcomes of PyCHA, particularly how they compare with those of HA and aTSA in young patients.

Acknowledgments

The authors acknowledge the New Zealand National Joint Registry for providing the data used in this study.

Disclaimers:

Funding: No funding was disclosed by the authors.
Conflicts of interest: The authors, their immediate families, and any research foundations with which they are affiliated have not received any financial payments or other benefits from any commercial entity related to the subject of this article.

References

1. Boileau P, Galvin JW, Pangaud C, Gonzalez J-F, Gauci M-O. Response to Letter to the Editor regarding: "Fracture of pyrocarbon humeral head resurfacing implant: a case report. J Shoulder Elbow Surg 2021;30:e134-5. https://doi.org/10.1016/j.jse.2020.11.005
2. Boileau P, Moineau G, Morin-Salvo N, Avidor C, Godenèche A, Lévigne C, et al. Metal-backed glenoid implant with polyethylene insert is not a viable long-term therapeutic option. J Shoulder Elbow Surg 2015;24:1534-43. https://doi.org/10.1016/j.jse.2015.02.012
3. Bryant D, Litchfield R, Sandow M, Gartsman GM, Guyatt G, Kirkley A. A comparison of pain, strength, range of motion, and functional outcomes after hemiarthroplasty and total shoulder arthroplasty in patients with osteoarthritis of the shoulder. J Bone Joint Surg 2005;87:1947-56. https://doi.org/10.2106/jbjs.d.02854
4. Castagna A, Garofalo R. Journey of the glenoid in anatomic total shoulder replacement. Shoulder Elbow 2018;11:140-8. https://doi.org/10.1177/1758573218790119
5. Cointat C, Raynier JL, Vasseur H, Lareyre F, Raffort J, Gauci MO, et al. Short-term outcomes and survival of pyrocarbon hemiarthroplasty in the young arthritic shoulder. J Shoulder Elbow Surg 2022;31:113-22. https://doi.org/10.1016/j.jse.2021.06.002
6. Dawson J, Rogers K, Fitzpatrick R, Carr A. The Oxford Shoulder Score revisited. Arch Orthop Traum Surg 2009;129:119-23. https://doi.org/10.1007/s00402-007-0549-7
7. Denard PJ, Wirth MA, Orfaly RM. Management of glenohumeral arthritis in the young adult. J Bone Joint Surg 2011;93:885-92. https://doi.org/10.2106/jbjs.j.00960
8. Dillon MT, Inacio MCS, Burke MF, Navarro RA, Yian EH. Shoulder arthroplasty in patients 59 years of age and younger. J Shoulder Elbow Surg 2013;22:1338-44. https://doi.org/10.1016/j.jse.2013.01.029
9. Fox TJ, Cil A, Sperling JW, Sanchez-Sotelo J, Schleck CD, Cofield RH. Survival of the glenoid component in shoulder arthroplasty. J Shoulder Elbow Surg 2009;18:859-63. https://doi.org/10.1016/j.jse.2008.11.020
10. Gao R, van der Merwe M, Coleman B, Boyle MJ, Frampton CM, Hirner M. Outcomes of reverse shoulder arthroplasty in patients under 55 years old: Results from the New Zealand joint registry. Shoulder Elbow 2022:17585732221104745. https://doi.org/10.1177/17585732221104745

11. Garret J, Godeneche A, Boileau P, Molé D, Etzner M, Favard L, et al. Pyrocarbon interposition shoulder arthroplasty: preliminary results from a prospective multicenter study at 2 years of follow-up. J Shoulder Elbow Surg 2017;26:1143-51. https://doi.org/10.1016/j.jse.2017.01.002
12. Gartsman GM, Roddey TS, Hammerman SM. Shoulder arthroplasty with or without resurfacing of the glenoid in patients who have osteoarthritis. J Bone Joint Surg Am 2000;82:26-34. https://doi.org/10.2106/00004623-200001000-00004
13. Gauci M-O, Winter M, Dumontier C, Bronsard N, Allieu Y. Clinical and radiologic outcomes of pyrocarbon radial head prosthesis: midterm results. J Shoulder Elbow Surg 2016;25:98-104. https://doi.org/10.1016/j.jse.2015.08.033
14. Gonzalez J-F, Alami GB, Baque F, Walch G, Boileau P. Complications of unconstrained shoulder prostheses. J Shoulder Elbow Surg 2011;20:666-82. https://doi.org/10.1016/j.jse.2010.11.017
15. Hudek R, Werner B, Abdelkawi AF, Gohlke F. Pyrocarbon interposition shoulder arthroplasty in advanced collapse of the humeral head. Der Orthopäde 2017;46:1034-44. https://doi.org/10.1007/s00132-017-3495-2
16. Klawitter JJ, Patton J, More R, Peter N, Podnos E, Ross M. In vitro comparison of wear characteristics of PyroCarbon and metal on bone: Shoulder hemiarthroplasty. Shoulder Elbow 2018;12:11-22. https://doi.org/10.1177/1758573218796837
17. Lo IKY, Litchfield RB, Griffin S, Faber K, Patterson SD, Kirkley A. Quality-of-life outcome following hemiarthroplasty or total shoulder arthroplasty in patients with osteoarthritis. A prospective, randomized trial. J Bone Joint Surg Am 2005;87:2178-85. https://doi.org/10.2106/jbjs.d.02198
18. Lorenzetti A, Streit JJ, Cabezas AF, Christmas KN, LaMartina J, Simon P, et al. Bone graft augmentation for severe glenoid bone loss in primary reverse total shoulder arthroplasty: Outcomes and evaluation of host bone contact by 2D-3D image registration. JB JS Open Access 2017;2:e0015. https://doi.org/10.2106/jbjs.oa.17.00015
19. Malhas AM, Granville-Chapman J, Robinson PM, Brookes-Fazakerley S, Walton M, Monga P, et al. Reconstruction of the glenoid using autologous bone-graft and the SMR Axioma TT metal-backed prosthesis: the first 45 sequential cases at a minimum of two years' follow-up. Bone Joint J 2018;100-B:1609-17. https://doi.org/10.1302/0301-620x.100b12.bjj-2018-0494.r1
20. McBride AP, Ross M, Hoy G, Duke P, Page R, Peng Y, et al. Mid-term outcomes of pyrolytic carbon humeral resurfacing hemiarthroplasty compared with metal humeral resurfacing and metal stemmed hemiarthroplasty for osteoarthritis in young patients: analysis from the Australian Orthopaedic Association National Joint Replacement Registry. J Shoulder Elbow Surg 2022;31:755-62. https://doi.org/10.1016/j.jse.2021.08.017
21. Mosillo G, Basso MA, Balato G, Bernasconi A, Coviello A, Tamborini F, et al. Adaptive proximal scaphoid implant (APSI): a systematic review of the literature. Orthop Rev 2021;14:30721. https://doi.org/10.52965/001c.30721
22. Nyring MRK, Olsen BS, Amundsen A, Rasmussen JV. Minimal Clinically Important Differences (MCID) for the Western Ontario Osteoarthritis of the Shoulder Index (WOOS) and the Oxford Shoulder Score (OSS). Patient Relat Outcome Meas 2021;12:299-306. https://doi.org/10.2147/prom.s316920
23. Pangaud C, Gonzalez J-F, Galvin JW, Gauci M-O, Boileau P. Fracture of pyrocarbon humeral head resurfacing implant: a case report. J Shoulder Elbow Surg 2020;29:e306-12. https://doi.org/10.1016/j.jse.2020.02.028
24. Pierrart J, Bourgade P, Mamane W, Rousselon T, Masmejean EH. Novel approach for posttraumatic panarthritis of the wrist using a pyrocarbon interposition arthroplasty (Amandys®): Preliminary series of 11 patients. Chir Main 2012;31:188-94. https://doi.org/10.1016/j.main.2012.07.011
25. Radnay CS, Setter KJ, Chambers L, Levine WN, Bigliani LU, Ahmad CS. Total shoulder replacement compared with humeral head replacement for the treatment of primary glenohumeral osteoarthritis: A systematic review. J Shoulder Elbow Surg 2007;16:396-402. https://doi.org/10.1016/j.jse.2006.10.017
26. Ricón FJ, Lajara F, Fuentes A, Aguilar ML, Boix A, Lozano JA. Pyrocarbon arthroplasty in acute unreconstructable radial head fractures: mid-term to long term results. J Orthop Traumatol 2018;19:13. https://doi.org/10.1186/s10195-018-0499-6
27. Sandow MJ, David H, Bentall SJ. Hemiarthroplasty vs total shoulder replacement for rotator cuff intact osteoarthritis: how do they fare after a decade? J Shoulder Elbow Surg 2013;22:877-85. https://doi.org/10.1016/j.jse.2012.10.023
28. Sarris IK, Kyrkos MJ, Galanis NN, Papavasiliou KA, Sayegh FE, Kapetanos GA. Radial head replacement with the MoPyC pyrocarbon prosthesis. J Shoulder Elbow Surg 2012;21:1222-8. https://doi.org/10.1016/j.jse.2011.12.004
29. Sperling JW, Cofield RH, Rowland CM. Minimum fifteen-year follow-up of Neer hemiarthroplasty and total shoulder arthroplasty in patients aged fifty years or younger. J Shoulder Elbow Surg 2004;13:604-13. https://doi.org/10.1016/j.jse.2004.03.013