

All-polyethylene, hybrid, and modern metal-backed glenoid components show relevant but not significantly different outcomes in anatomic total shoulder arthroplasty: A systematic review

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ABSTRACT

Introduction: Anatomic total shoulder arthroplasty (aTSA) is one of the most common orthopedic procedures performed in the United States, with all-polyethylene (PE) glenoid components long being recognized as the gold standard for total shoulder arthroplasty (TSA) implant design. However, the emergence of modern metal-backed glenoid (MBG) and hybrid glenoid implant designs offers alternatives to the traditional construct. The purpose of this systematic review is to investigate the difference in clinical and radiographic outcomes between the three glenoid component designs.

Methods: Following PRISMA guidelines, this systematic review grouped included studies as all-polyethylene (n = 19), hybrid (n = 5), and MBG (n = 13). Primary outcomes assessed radiolucency, complication rates, revision rates, range of motion (ROM), and patient-reported outcomes (PROMs). Between-group comparisons were performed across the three cohorts.

Results: No significant difference was found between the MBG, all-polyethylene, and hybrid glenoid implant groups in radiolucency (P = 0.30) and revision rates (P = 0.28). Additionally, between the three implant designs, no significant difference was observed in any PROMs or ROM measurements. Meta-regression revealed longer follow-up times were associated with increased reported revision, complication, and radiolucency rates (P < 0.001 for all).

Conclusion: In anatomic TSA, hybrid, cemented all-polyethylene, and modern metal-backed implant designs did not demonstrate statistically significant differences in radiolucency, complications, revisions, PROMs, or ROM. However, meta-regression results suggest follow-up duration may be associated with higher reported revision, complication, and radiolucency rates. Because the hybrid and modern metal-backed literature is relatively novel and follow-up is less standardized, these comparative findings should be considered preliminary. Non-significant but higher complication and revision estimates in the PE group merit continued monitoring. Given the increasing utilization of aTSA, additional long-term comparative studies with defined standardized outcomes and implant-stratified reporting are necessary to provide a more definitive analysis of glenoid implant performance.

1. Introduction

Anatomic total shoulder arthroplasty (aTSA) has become an increasingly common procedure over the past several decades, with approximately 823,361 people living with a shoulder replacement in the United States in 2017.¹ Total shoulder arthroplasties (TSAs) are a safe

and effective procedure most commonly performed for glenohumeral osteoarthritis.^{2–5} Although reverse total shoulder arthroplasty has become increasingly utilized over recent years, anatomic shoulder arthroplasty remains clinically relevant.^{6–8} Glenoid components for TSA were first designed by Dr. Neer in 1974 and have since undergone substantial design changes, highlighted by differences in composition and configuration.^{9,10} First generation glenoid components were

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Abbreviations:

- TSA Total shoulder arthroplasty
- aTSA Anatomic total shoulder arthroplasty
- PE All-polyethylene
- MBG metal-backed glenoid
- RSA Reverse shoulder arthroplasty

cemented and all-polyethylene keeled prostheses, eventually prompting variations of the implant, such as pegged and conforming designs.¹⁰ All-polyethylene (PE) glenoid components used in TSA are clinically and radiographically effective during short-term and mid-term follow-ups, however, concerns of long-term implant loosening, and failure has led to alterations of the traditional construct.^{11,12}

In an effort to improve upon all-polyethylene implants, metal-backed glenoid (MBG) components were implemented. However, early studies using first-generation cementless metal-backed designs for TSA showed significantly higher rates of loosening and failure in comparison to all-polyethylene, likely due to lack of bony fixation and failure of the polyethylene attachment to the metal base.^{13–16} Nevertheless, the metal and polyethylene composite design was revised and subsequent clinical trials utilizing the second-generation implant demonstrated satisfactory to excellent clinical performance and function.¹⁷ Another emerging glenoid design that has shown promise has been hybrid glenoid components. Like metal-backed components, hybrid prostheses are composed of a mixture of polyethylene and metal materials. However, hybrid designs include a metal central post with polyethylene peripheral pegs or a metal central post with metal peripheral pegs. A 2022 systematic review analyzed the effectiveness of hybrid glenoid components in aTSA and found that hybrid designs were non-inferior to all-polyethylene glenoid designs in regards to ROM and patient-reported outcomes.¹⁸ Furthermore, a recent study investigated the clinical differences between implant options for TSA, finding similar patient reported outcomes between the three groups.⁸

Although prior systematic reviews have evaluated hybrid glenoid components, a systematic review providing a three-cohort synthesis that aggregates and compares outcomes across cemented all-polyethylene glenoid (PE), hybrid, and modern metal-backed glenoid components in anatomic total shoulder arthroplasty remains limited. The objective of this systematic review is to investigate the difference in clinical and radiographical outcomes between the three glenoid component designs. We hypothesized that no statistically significant differences would be detected in clinical and radiographic outcomes among hybrid, modern metal-backed, and all-polyethylene glenoid components in the setting of aTSA.

2. Methods

This review was performed according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines for reporting systematic reviews.¹⁹

2.1. Search strategy

This study was registered on the PROSPERO International Prospective Register of Systematic Reviews (CRD42024498501) database. Articles were gathered from PubMed, Cochrane, and Google Scholar databases. The initial search was conducted in September of 2024. The search strategy aimed to identify studies utilizing hybrid, MBG, and all-poly implants. Examples of search terms included: “hybrid” OR “total” OR “shoulder” NOT “reverse” NOT “rsa” for the hybrid implant studies, “all-polyethylene” AND “total” OR “shoulder” NOT “reverse” NOT “rsa” for the cemented, all-polyethylene implant studies, and “metal-backed”

OR “total” OR “shoulder” NOT “reverse” NOT “rsa” for the metal-backed implant studies.

2.2. Eligibility and study selection

Two reviewers (S.I. and C.H.) screened titles, abstracts, and full texts of retrieved studies, with a third reviewer (M.H.) resolving any disagreements. Studies were selected based on the following inclusion and exclusion criteria. The inclusion criteria were: (i) papers evaluating clinical and/or radiographic outcomes of hybrid, modern metal-backed, or cemented, all-polyethylene glenoid implants in the setting of aTSA, (ii) published in English language, and (iii) full-text available. Exclusion criteria were: (i) not published within the last twelve years, (ii) scientific conference abstract, literature review, article, cadaveric study, and biomechanical study (iii) published in a non-English language, and (iv) utilized non-modern metal-backed designs.

To define “hybrid glenoid” components, implants were included if they utilized a cage design or a combination of polyethylene and metal fixation components. Designs included (i) Zimmer Biomet Regenerex Hybrid Glenoid, (ii) Equinox Cage Glenoid (Exactech), and (iii) Biomet Comprehensive Shoulder System. Modern metal backed designs included: (i) The second-generation Systema Multiplana Randelli MBG (LimaCorporate); (ii) the Zimmer Biomet second-generation Trabecular Metal glenoid, and (iii) Arthrex cementless convertible glenoid component. Due to the wide variation in all-polyethylene implant types, specific design models were not clarified for the study.

2.3. Data extraction

Data was extracted according to the following categories: (1) study information: author, publication year, follow-up, and study type; (2) Patient baseline characteristics: gender and age; (3) implant type; (4) range of motion; (5) complication rates; (6) revision rates; (7) radiolucency rates; and (8) other outcome measures.

2.4. Risk of bias assessment

Two reviewers (S.I. and C.H.) independently used the Methodological Index for Nonrandomized Studies (MINORS) score to assess quality.²⁰ Score discrepancies were resolved through a third independent reviewer (M.H.). The MINORS checklist consists of 8 items for non-comparative studies and 4 additional items for comparative studies (Supplemental Table). Non-comparative studies are scored out of 16 points, while comparative studies are scored out of 24 points. For non-comparative studies, the scores are as follows: 0-4 indicates very low quality, 5-8 indicates low quality, 9-12 indicates moderate quality, and 13-16 indicates high quality. For comparative studies, the scores are as follows: 0-6 indicates very low quality, 7-12 indicates low quality, 13-18 indicates moderate quality, and 19-24 indicates high quality.

2.5. Statistical analysis

To compare outcomes across the all-polyethylene, metal-backed, and hybrid glenoids, an analysis of variance (ANOVA) test was conducted utilizing SAS software (Version 9.4; SAS Institute Inc., Cary, NC). This specific approach was selected for concurrent comparison of mean values between the three groups to determine statistically significant differences. Weighted univariable meta-regression was performed to assess the influence of follow-up duration on complication, revision, and radiolucency rates. Analyses were weighted by inverse variance and conducted using SPSS (Version 31; IBM Corp., Armonk, NY). Statistical significance was set at $p < 0.05$.

3. Results

3.1. Literature search results

The literature search in the relevant databases yielded 674 results for the cemented, all-polyethylene implant group, 460 studies for the hybrid implant group, and 236 for the MBG group. After removing duplicates and studies with unrelated subject material, the full text for 36 cemented PE papers, 9 hybrid papers, and 15 MBG papers were assessed for eligibility.

Additional studies were excluded upon further review as they did not meet the inclusion criteria. In total, 19 studies were included in the cemented PE group, 5 studies were included in the hybrid group, and 13 studies were included in the MBG group (Fig. 1). Mean follow-up (minimum mean follow-up) was 61.4 months (24.0) for PE, 37.4 months (4.3) for hybrid, and 57.5 months (32.6) for MBG.

3.2. Demographics

The average age was 64.1 years (range, 60.7-65.7) for the hybrid group, 65.5 (range, 55-71.3) for the PE group, and 66.2 (range, 60.6-73.4) for the MBG group. There was no significant difference in age between the three groups ($P = 0.43$). The average body mass index was 31.05 (range, 29.9-32.2) for the hybrid group, 28.45 (range, 25.6-30.0) for the PE group, and 29.9 (range, 26.5-32.7) for the MBG group. Similarly, BMI did not differ significantly between the three groups ($P = 0.42$). A summary of the demographic characteristics for each study can be found in Table 1.

3.3. Risk of bias

There were 23 noncomparative studies and 14 comparative study included in this review. None of the studies received full scores according to the MINORS criteria. The mean MINORS score for all non-comparative studies was 10.2, indicating overall moderate study quality. The mean MINORS score for all comparative studies was 18.1, indicating overall moderate study quality. Further information on individual study scoring according to the MINORS criteria can be referenced in the Appendix.

3.4. Patient-reported outcomes

3.4.1. ASES

Mean ASES scores were measured in 8 MBG studies, 5 Hybrid studies, and 8 PE studies. There was no statistically significant difference in the post-op values between the three groups ($F(2, 19) = 0.64, P = 0.54$). Additionally, pairwise comparison between the three groups showed no significant difference at the 0.05 level (Fig. 2).

3.4.2. VAS

Mean VAS scores were measured in 5 MBG studies, 4 Hybrid studies, and 6 PE studies. No statistical difference was found within the post-operative VAS scores between the 3 groups ($F(2, 12) = 0.39, P = 0.69$) (Fig. 2). No significant differences were found at the 0.05 level on pairwise comparison between the three groups (Table 2).

3.4.3. Constant

Data points for post-operative Constant values were limited as well, with only hybrid and MBG values compared. No statistical significance was found between the two groups at the $P < 0.05$ threshold ($F(1,2) = 10.38, P = 0.08$) (Fig. 2).

3.5. Range of motion

3.5.1. External rotation

Mean external rotation scores were measured in 3 MBG studies, 4 Hybrid studies, and 10 PE studies. No significant difference was found amongst the three groups ($F(2, 16) = 0.34, P = 0.72$) (Fig. 2). Pairwise comparisons between each group also showed no significant difference at the 0.05 level (Table 2).

3.5.2. Forward flexion

Due to limited data points for post-operative forward flexion, only the hybrid and MBG were compared. The test demonstrated no statistical difference in mean post-operative values at the $P < 0.05$ threshold ($F(1,11) = 0.66, P = 0.43$) (Fig. 2).

3.5.3. Abduction

Due to limited data points, only MBG and hybrid post-operative values were compared. No statistically significant difference was observed between the two groups at the $P < 0.05$ threshold ($F(1,4) =$

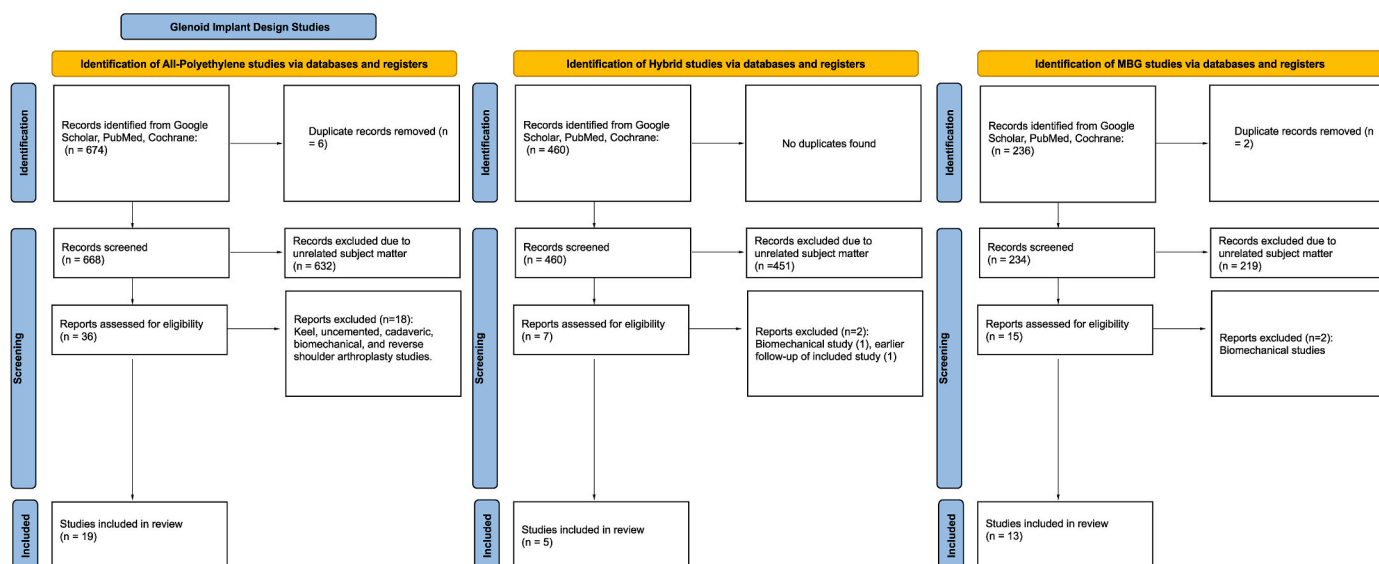


Fig. 1. PRISMA diagram of literature search for cemented All-Polyethylene, Hybrid, and MBG glenoid implant designs.

Table 1
Patient demographics and study characteristics.

Author	Year	Gender (M: F)	Study Type	Implant Type	Age (years)	FU (months)	Participants
Hybrid Implant Design							
Gulotta et al. ²¹	2015	23:20	R	ZB Regenerex Hybrid Glenoid	66.3 ± 8.9	38	43
Grey et al. ²²	2015	27:19	P	Equinox Cage Glenoid (Exactech)	63.2 ± 9.4	25.2 ± 4.8	46
Nelson et al. ²³	2018	NR	CS	Biomet Comprehensive Shoulder System	64.7	66.5	45
Marigi et al. ²⁴	2022	363:350	R	Comprehensive Shoulder System (Hybrid Modular)	60.7 ± 6.3	4.3 ± 1.5	666
Friedman et al. ²⁵	2023	460:506	R	Equinox Cage Glenoid (Exactech)	65.7 ± 8.7	53	981
All -Poly Implant Design							
Merolla et al. ²⁶	2014	11:11	P	NR	66	31	22
Grey et al. ²²	2015	27:19	R	Aequalis PE	62.2	25.5 ± 4.8	46
Gulotta et al. ²¹	2015	22:18	R	ZB PE	68.2 ± 9.1	38.4	40
Noyes et al. ²⁷	2015	27:15	R	DePuy Global Advantage PE	64	80	42
Merolla et al. ¹⁷	2016	15:13	P	Aequalis PERFORM Cortiloc™, Tornier SAS, Montbonnot Saint Martin, France	62.3 ± 8.9	31 ± 3.2	28
Wijeratna et al. ²⁸	2016	32:45	R	DePuy Synthes Global Advantage, Global AP with an Anchor Peg	68.6	46.7	77
Parks et al. ²⁹	2016	40:35	R	Affiniti CortiLoc glenoid	63.5	34 (RA), 28.7 (C)	75
McLendon et al. ³⁰	2017	146:141	R	Cofield II PE	65	86.4	287
Kilian et al. ³¹	2018	11:11	P	Aequalis PE	67 ± 9	34 ± 13	22
Moulton et al. ³²	2019	13:7	R	Arthrex Univers II	62.4 ± 7.4	79	20
Chin et al. ³³	2021	23:24	P	ZB PE	68.4 ± 5.5	24	47
Borbas et al. ³⁴	2021	49:28	R	DePuy Synthes Anchor Peg Glenoid	68	101	77
Simon et al. ³⁵	2022	42:50	P	Affinis® double pegged	68.1 ± 7.1	U	92
Matsui et al. ³⁶	2023	3:13	R	DePuy Synthes Global Advantage, Zimmer Bigliani/Flatow complete shoulder prosthesis	61	137	16
Friedman et al. ²⁵	2023	245:279	R	NR	67.3 ± 8.4	66.4	524
Kim et al. ³⁷	2023	8:24	R	NR	66.9 ± 11.2	49.3 ± 21.8	32
Haque et al. ³⁸	2023	18: 80	R	ZB PE	71.3	61.2	98
Magosch et al. ³⁹	2023	7:13	R	Arthrex Pegged Glenoid	69.3 ± 6.8	60.0 ± 18.5	20
MBG Implant Design							
Budge et al. ⁴⁰	2013	5:14	P	2nd trabecular metal glenoid	62.8 ± 14.6	38	19
Merolla et al. ¹⁷	2016	24:16	P	2nd trabecular metal glenoid	63.8 ± 7.3	38 ± 2.9	40
Styron et al. ⁴¹	2016	38:28	R	2nd trabecular metal glenoid	66.2	50.2 (C), 20.5 (RA)	66
Panti et al. ⁴²	2016	26:40	CS	2nd trabecular metal glenoid	69.76	43.2	66
Endrizzi et al. ⁴³	2016	NR	P	2nd trabecular metal glenoid	67.5 ± 8.6	50.8 (RA); 53.1 (C)	68
Merolla et al. ¹⁷	2016	24:16	R	2nd trabecular metal glenoid	63.8	38 ± 2.9	40
Gurin et al. ⁴⁴	2017	NR	CS	2nd trabecular metal glenoid	NR	100	80
Watson et al. ⁴⁵	2018	NR	CS	2nd trabecular metal glenoid	66.36	41	36
Magosch et al. ³⁹	2021	12:8	P	Cementless MB convertible Universal Glenoid™ component (Arthrex Inc.)	73.4	55.3	20
Chen et al. ⁴⁶	2021	18:9	R	2nd trabecular metal glenoid	68.8	80	27
Murphy et al. ⁴⁷	2022	29:6	R	2nd trabecular metal glenoid	62	86.6	35
Kim et al. ³⁷	2023	8:10	R	2nd convertible metal glenoid	60.6	32.6	18
Chin et al. ⁴⁸	2024	24:22	P	2nd trabecular metal glenoid	66.5 ± 6.4	60	46
Dipasquale et al. ⁴⁹	2024	NR	R	Modern Convertible metal-backed glenoid component	NR	NR	26

FU, Follow Up; RA, Radiographic; C; Clinical; R, Retrospective; P, Prospective; CS, Case Series; ZB, Zimmer-Biomet; NR, Not Reported; PE, Polyethylene.

0.01, $P = 0.94$) (Fig. 2).

3.6. Radiolucency

A one-way ANOVA test was utilized to analyze the difference between prevalence of radiolucency between the three groups. No statistically significant difference was found between the three groups at the $p < 0.05$ threshold ($F(2,24) = 1.28, P = 0.30$). Root mean square error was found to be 45.42 with an R^2 value of 0.0996 (Fig. 3).

3.7. Complications

Complication rates were measured across the three implant groups. The cemented PE group displayed the highest complication rate at 11.0%. The hybrid and MBG groups had complication rates of 7.4% and 7.8%, respectively (Table 3). A one-way ANOVA test was utilized to analyze the difference among complication rates. Although the PE

complication rate (11.0%) exceeded those of MBG (7.8%) and hybrid (7.4%) by 3.2 and 3.6 percentage points respectively, the overall difference among the three groups was not statistically significant ($F(2,25) = 0.20, P = 0.82$). Additionally, pairwise comparisons were not statistically significant at the $P < 0.05$ level (Fig. 4A).

3.8. Revision surgeries

Revision rates were measured across the three implant groups. The MBG group produced the lowest revision rate at 2.0% while the cemented PE group produced the highest revision rate of 8.4%. The hybrid implant group produced a revision rate of 3.0% (Table 4). To compare revision rates among the three groups, a one-way ANOVA test was done. Although the PE revision rate (8.4%) exceeded MBG (2.0%) and hybrid (3.0%) by 6.4 and 5.4 percentage points respectively, overall, no statistically significant difference was found between the three implant types ($F(2,29) = 1.32, P = 0.28$). Pairwise comparisons found

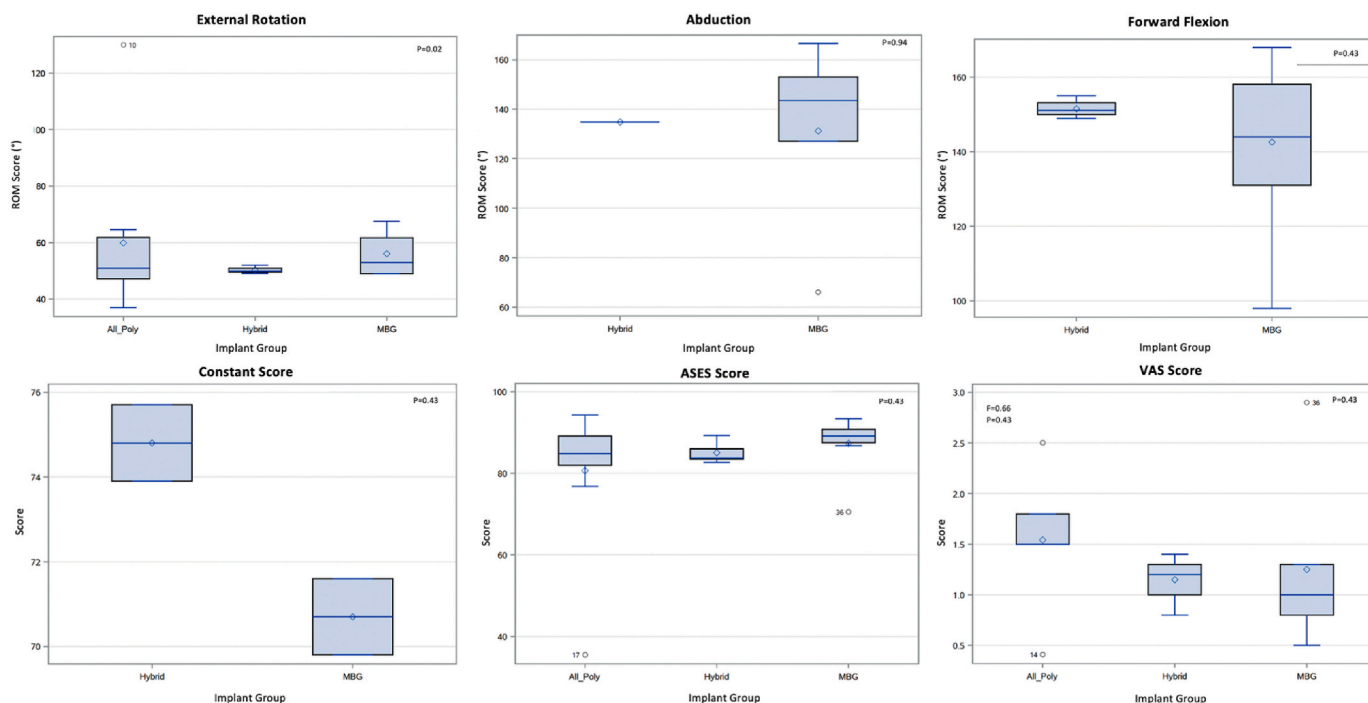


Fig. 2. Distribution of PROMs and ROM measurements across glenoid implants. Box plots display external rotation, abduction, forward flexion, constant score, ASES score, and VAS Score across all-polyethylene, hybrid, and modern metal-backed glenoid implant types. Range of motion values are displayed in degrees. No statistically significant differences were observed between groups ($p > 0.05$).

Table 2
Pairwise comparisons of ASES, VAS, External Rotation scores.

Outcome	Comparison	MD	95% CI (Lower, Upper)
ASES Score	MBG vs. Hybrid	2.2	(-15.5, 20.1)
	MBG vs. All-Poly	6.6	(-8.5, 21.3)
	Hybrid vs. All-Poly	4.4	(-13.0, 21.9)
VAS Score	MBG vs. Hybrid	0.1	(-1.1, 1.3)
	MBG vs. All-Poly	-0.2	(-1.4, 0.8)
	Hybrid vs. All-Poly	-0.3	(-1.6, 0.8)
External Rotation (°)	MBG vs. Hybrid	5.7	(-28.7, 40.3)
	MBG vs. All-Poly	-3.8	(-32.0, 24.3)
	Hybrid vs. All-Poly	9.6	(-40.1, 20.8)

MD, Mean Difference. No comparisons reached statistical significance (all $p > 0.05$).

no statistically significant difference between the rates at $P < 0.05$ level, as well (Fig. 4B).

3.9. Meta regression analysis

Weighted univariable meta-regression demonstrated significant time-dependent effects for complication rates, revision rates, and radiolucency rates. Follow-up duration explained 3.7 % of variation in complication rate ($\beta = 0.19, P < 0.001$), 25.9 % in revision rate ($\beta = 0.51, P < 0.001$), and 35.4 % in radiolucency rate ($\beta = 0.60, P < 0.001$). These findings indicate that longer study follow-up strongly influences

Table 3
Complication rates across glenoid implant types.

Implant Group	Total Patients	Complications	Complication Rate (%)
MBG	486	38	7.8
All-Poly	1140	125	11.0
Hybrid	1816	134	7.4

No statistically significant difference in complication rates between groups (all $p > 0.05$).

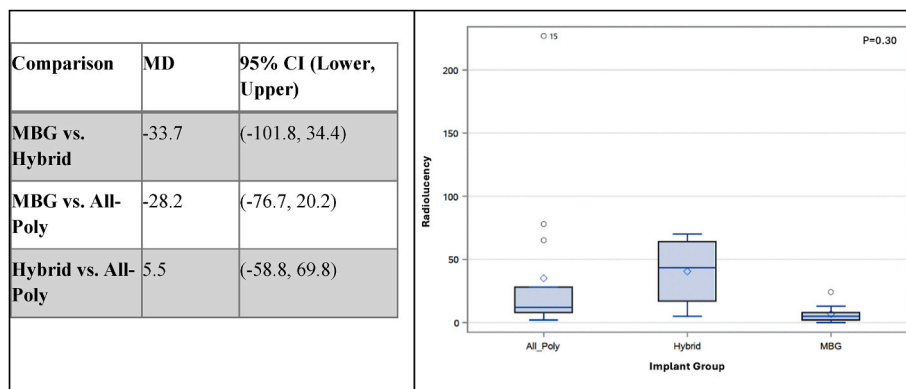


Fig. 3. Radiolucency rates across glenoid implants. Pairwise mean difference (MD) and box plot distributions show no statistically significant differences between metal-backed, hybrid, and all-polyethylene glenoid implant types. No comparison reached statistically significant difference ($p > 0.05$).

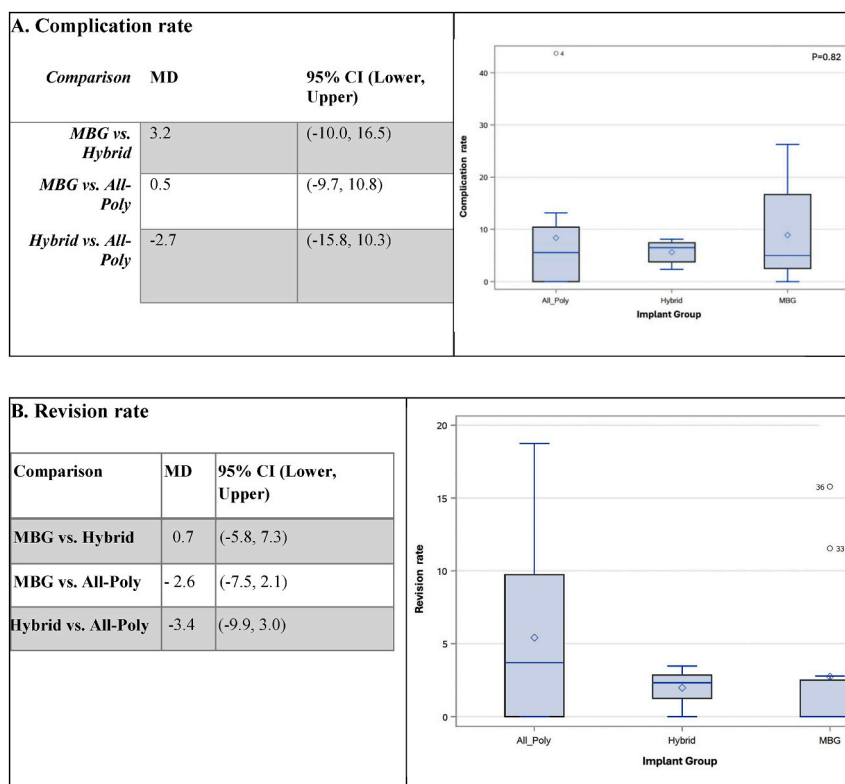


Fig. 4. Postoperative (A) complication and (B) revision rates across glenoid implants. Mean difference (MD) and box plot distribution indicate no significant difference in reported complication and revision rates between all-polyethylene, hybrid, and metal-backed glenoid implants. No between-group differences were statistically significant ($p > 0.05$).

Table 4
Revision rates across glenoid implant types.

Implant Group	Total Patients	Revision Surgeries	Revision Rate (%)
MBG	538	11	2.0
All-Poly	1506	127	8.4
Hybrid	1816	55	3.0

revision and radiographic outcomes, underscoring the importance of duration-adjusted comparisons across implants.

4. Discussion

A variety of glenoid implant designs have been developed in the setting of aTSA to address the need for improved implant longevity and optimization of patient outcomes. The main finding of this systematic review is that there are no significant differences in radiolucency, revision rates, PROMs, and ROM between all-polyethylene, hybrid, and metal-backed glenoid implant designs in aTSA. The absence of statistically significant differences should not be interpreted as evidence of equivalence. However, the results of this study should be interpreted within the context of variable follow-up periods. To further explore potential influence of follow-up duration, a meta regression was performed which was notable for significant time-dependent effects on complication, radiolucency, and revision rates. Specifically, longer follow-up times were associated with higher reported rates of complications, revisions, and radiolucency. These findings emphasize the importance of standardized follow-up times when comparing long term outcomes between the three implant groups.

When comparing the radiolucency lines between the cemented PE, MBG, and hybrid implant groups, no statistically significant difference in the prevalence of radiolucency was found between the three groups

($P = 0.30$). Interestingly, in a 2020 systematic review that compared modern metal-backed components to cemented PE, it was found that MBGs had lower radiolucency, loosening, and failure rates at a follow-up period greater than 72 months.¹¹ There are only a few studies utilizing hybrid glenoid designs as they are relatively novel in the setting of TSA, making radiolucency data with extended follow-up periods sparse. However, as more studies are published utilizing hybrid and MBG designs, a more definitive conclusion can be made regarding its association with radiolucency. The relatively novel nature of hybrid glenoid studies contributes to the lack of standardized follow-up in these studies, however, their inclusion provides preliminary comparative data. Overall, longer-term follow-up is needed before firm conclusions about comparative performance can be made.

PROMs from the included studies were aggregated and showed no significant differences as well. As the majority of studies included measured at least one PROM, our findings suggest that the glenoid design may not be directly correlated to a significant improvement in patient outcomes. Nevertheless, all three cohorts did demonstrate significant improvements between pre- and post-operative figures. With the increasing diversification of materials used in glenoid manufacturing, such as newer composite metal and vitamin E polyethylene, the PROMs measured in our study provide a benchmark for future studies on novel implants. While our results demonstrate that design differences may not impart a significant difference in PROMs at up to 137 months, continued monitoring may show emerging trends, especially with concerns for material fracture and off-axis deviation between peripheral pegs and central cage components in a hybrid cage implant.^{50,51} Regardless, the results from this study do not demonstrate that implant selection is a significant differentiator in patient outcomes or strength among groups receiving a hybrid cage, metal-backed or all-polyethylene implant for TSA. With follow-up intervals ranging from 4.3 to 137 months, the results are not standardized, however they offer insight into PROMs in a variety of post-operative settings.

The lack of a difference between the three styles included in this study was further demonstrated through a lack of significant differences found in the clinical ROM measurements. Although studies that included measurements did not report results in a consistent format, the measurements that were able to be included did not show any significant differences. When taken in the context of PROMs similarly lacking a significant difference between the three groups, the role of implant material and geometry may not be a primary driver of positive results.

It is therefore necessary to consider how other factors, such as cementation technique, may act as a key variable in long-term outcomes. In one biomechanical study, full cementation exhibited more resistance to glenoid motion than hybrid and interference fit, however there was no difference between hybrid and interference fixation.⁴⁵ In the context of this study, it may be more important to consider the cementation methods used in the fixation of the various implant bodies. This is further strengthened by the prevailing opinion that glenoid micromotion has been identified as the primary driver of unfavorable patient outcomes.⁵² Essentially, the results of this study may encourage focus to be shifted to the fixation method as opposed to implant architecture when determining areas for potential improvement.

Regarding revisions and complications, this review found no statistically significant difference between overall and pairwise comparison of revision and complication rates among the three implants. Although not statistically significant, the PE group showed higher complications (11% vs 7.8% MBG and 7.4% hybrid) and revisions (8.4% vs 2.0% and 3.0%). These differences may be clinically relevant and warrant continued surveillance. Notably, revision rates can sometimes serve as an incomplete surrogate for implant failure, particularly for MBG components, because the threshold to revise can be influenced by surgical complexity and anticipated glenoid bone loss.^{53,54} Overall, this is further supported by a finite element analysis that compared the mechanical behavior of hybrid glenoid implants to all-polyethylene implants which found similar stresses and identical risks for fatigue failure between the bone-cement interface of both implant designs.⁵⁵

On the contrary, Papadonikolakis et al. published a systematic review in 2014 comparing metal-backed and all-polyethylene rates of failure for glenoid components which demonstrated that metal-backed prostheses failed at significantly higher rates.⁵⁶ The discrepancy with our results may be attributed to the follow-up periods evaluated, as Papadonikolakis et al. focused on long-term failure rate. The 2014 study evaluated all metal-backed designs up to the year 2013, which excluded newer generation designs. Our meta regression results support this as it appears that longer study follow-up is independently associated with higher reported revision and complication rates. This outcome suggests that variability amongst the results of included studies may exist due to differences in follow-up times, further emphasizing the importance of contextual interpretation of revision and complication data. However, while it appears overall complication rate is low amongst the three groups, more detailed studies are required to evaluate long-term complication rates, specifically for newer generation MBG and hybrid implants.

This study has several limitations. One limitation was the lack of high-quality papers with prolonged follow-up times, as this hindered our ability to draw definitive conclusions in analyzing the clinical and radiographic results. Moreover, even at the upper end of included literature (up to 137 months), later mechanisms of failure after aTSA, such as aseptic glenoid loosening and rotator cuff failure, may be underrepresented.^{2,52} The follow-up times within the included studies were also inconsistent amongst the selected cohort, making direct comparison between the three groups difficult. This variation in follow-up periods prevents definitive conclusions from being made regarding long-term outcomes, however, as additional studies are conducted, these concerns should be addressed. Also, while our meta regression attempted to account for follow-up times, a variety of surgical techniques and implant types were utilized throughout the included studies which further restricted direct analysis. Another limitation

included an imbalanced and variable number of studies for each implant (19 for all-polyethylene, 13 for modern metal-backed, and 5 for hybrid) which may limit the statistical validity. Additionally, the included studies utilized diverse methodologies to measure relevant outcomes. This especially became an issue during the extraction of radiological results, as the variance in analysis was particularly prevalent. To combat this inconsistency, radiographic results were only used from studies that explicitly stated the percentage or total number of patients that exhibited radiolucency. Inconsistent methodologies and data collection also precluded the inclusion of certain valuable parameters, such as internal rotation measurements. Lastly, insufficient data points prevented consistent three-way comparisons across all outcomes limiting data analysis.

5. Conclusion

In anatomic TSA, hybrid, cemented all-polyethylene, and modern metal-backed implant designs did not demonstrate statistically significant differences in radiolucency, complications, revisions, PROMs, or ROM. However, results from our meta-regression suggest follow-up duration may be associated with higher reported revision, complication, and radiolucency rates. Because the hybrid and modern metal-backed literature is relatively novel and follow-up is less standardized, these comparative findings should be considered preliminary. Non-significant but higher complication and revision estimates in the PE group merit continued monitoring. Given the increasing utilization of aTSA, additional long-term comparative studies with defined standardized outcomes and implant-stratified reporting are necessary to provide a more definitive analysis of glenoid implant performance.

Informed consent

As this was a systematic review of published literature, there were no patients to consent.

Ethics in publishing statement

This research presents an accurate account of the work performed, all data presented are accurate and methodologies detailed enough to permit others to replicate the work.

This manuscript represents entirely original works and or if work and/or words of others have been used, that this has been appropriately cited or quoted and permission has been obtained where necessary.

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All authors have been personally and actively involved in substantive work leading to the manuscript and will hold themselves jointly and individually responsible for its content.

Credit author statement

Saad Ibrahim: Conceptualization (supporting), Data curation (lead), Formal Analysis (equal), Investigation (lead), Methodology (lead), Project Administration (lead), Visualization (lead), Writing-Original Draft(lead), **Chandler Harris:** Data curation (supporting), Investigation (supporting), Methodology (supporting), Writing-Original Draft (supporting) **Maxwell Harrell:** Data curation (supporting),

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Appendix A. Supplementary data

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