Journal of Arthroscopy and Joint Surgery 6 (2019) 9–20

Contents lists available at ScienceDirect

Journal of Arthroscopy and Joint Surgery

journal homepage: www.elsevier.com/locate/jajs

Management of glenohumeral arthritis in the young patient – A systematic review

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ARTICLE INFO

Article history:
Received 5 November 2018
Accepted 1 January 2019
Available online 4 January 2019

Keywords:
Shoulder
Osteoarthritis
Degenerative disease
Shoulder arthroplasty
Shoulder replacement
Glenoid resurfacing

ABSTRACT

Introduction: Glenohumeral joint degeneration in young patients has varying aetiology and provides a challenging clinical problem whose management is controversial. This review aims to provide an overview of the surgical options for managing these young patients.
Methods: A systematic review of the literature was conducted in accordance with the PRISMA guidelines using the online databases Medline and EMBASE. Cases series and comparative studies reporting on surgical interventions for glenohumeral joint degeneration in young patients (<65 years or a mean age <60 years) were included. Robustness of study methodology was appraised using the Methodological index for non-randomised studies.
Results: 30 eligible studies were identified; 10 hemiarthroplasty (HA) and glenoid resurfacing, 4 HA and glenoid reaming, 4 total shoulder arthroplasty (TSA), 3 glenoid resurfacing, 3 arthroscopic debridement, 3 reverse shoulder arthroplasty (RSA), 2 humeral resurfacing and 1 pyrocarbon interposition arthroplasty. Arthroscopic treatments reported good post-operative functional results, but revision rates ranged from 15.8% to 22% at short term follow-up. Although HA and glenoid resurfacing provided an improvement in functional scores, a high revision rate was reported in most studies (9.1%–77%) which was higher than after HA and glenoid reaming (2.8%–16.7%) and humeral resurfacing (2%–12%). TSA was reported to improve the mean Constant Score from 34 to 64 but glenoid loosening ranged from 17.6% to 43.8% and revision rate 6.5%–34% across the studies.
Conclusion: Surgical intervention in young patients with glenohumeral degeneration carries higher risk of failure and subsequent need for potentially complex revision surgery. Therefore, non-operative measures should be exhausted and patients adequately counselled prior to proceeding to arthroplasty.

1. Introduction

The presence of glenohumeral joint degeneration in young and active individuals provides the treating clinician with a challenge. Their increased functional demands and expectations requires surgical reconstruction to have greater durability.[1] In young patients the prospect of early revision within 10 years needs to be considered and thus the choice of implants and surgical technique may differ from the older patient. The aetiology of early degenerative change is varied and can be secondary to trauma, surgery, avascular necrosis, glenoid dysplasia, infection and chondrolysis.

Traditional conservative management has included physiotherapy, activity modification and analgesics. Conservative measures are preferred initially as they subject patients to minimal risk but the evidence to support the different treatments and their ability to alter disease progression is limited.[2] Although there is strong evidence for the use of paracetamol, anti-inflammatory and opiates medications for osteoarthritis in general, they all have specific adverse effects that need to be considered.[3–6] There is no available evidence to support the routine use of corticosteroid injections in shoulder arthritis[7] and sodium hyaluronate has only been shown to reduce pain at short term follow up.[8] Previous Cochrane reviews have highlighted the limited available evidence for both physiotherapy and injections in shoulder pain.[9,10] Both suprascapular nerve block and acupuncture have been shown to improve symptoms in general shoulder pain but specific studies on osteoarthritis are lacking.[11,12] There is little reported on the outcome of biologics and cell therapy in the shoulder[13,14] unlike the progress being made in certain types of early cartilage loss in the knee. It is likely that patients who are young and active will have a prolonged period of observation coupled with activity modification before the option of surgery is considered.

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https://doi.org/10.1016/j.jajs.2019.01.005
2214-9635/

Surgical options after failed conservative management include arthroscopic debridement, biological resurfacing, hemiarthroplasty (HA), total shoulder arthroplasty (TSA), reverse shoulder arthroplasty (RSA) and shoulder arthrodesis. Arthroscopic debridement has been proposed in patients with concentric wear, residual joint space of more than 2 mm and only mild loss of range of motion.[15] Limited reports are available on microfracture of isolated cartilage loss on the humeral head or glenoid however few authors see this treatment as affording any long-term benefits to patients.[16,17] Although an option, shoulder arthrodesis is unattractive to the younger patient due to the possibility of persistent peri scapular pain, stress on musculature and acromioclavicular joints combined with marked loss of motion.[18]

For these reasons it is not surprising that the number of arthroplasties being undertaken in young patients is increasing at a rate of 8.2% per year[19] despite age under 60 being associated with poorer outcomes.[20–24] TSA carries the risk of glenoid loosening which accounts for 39% of all complications[25] and has been reported in 73% of patients at 15–20 years follow up.[26] HA can cause glenoid arthritis, posterior humeral subluxation and posterior glenoid erosion.[21, 22, 27–29] Previous studies have demonstrated that TSA provides superior results to HA in terms of pain and function[30–33] leading to a trend to increased TSA compared to HA in young patients.[19] Biological resurfacing of the glenoid has been proposed as an additional technique to HA to avoid metal-on-bone contact and delay glenoid erosion. Despite RSA becoming increasingly used in older populations, the majority advocate that it should be used with care in younger patients and those with high functional demands.[34,35]

In this young population it is important to consider the requirement for future revision procedures given the challenges of revision in the presence of significant bone loss.[36,37] In addition, the revision of a failed HA to TSA has been shown result in inferior to those achieved after primary TSA.[38,39] The aim of this study was to provide an overview of the surgical options for managing young patients with glenohumeral joint degeneration, with particular respect to survivorship.

2. Methods

A systematic review of the literature was conducted in accordance with the PRISMA guidelines [40] using the online databases Medline and EMBASE. The review was registered on the PROSPERO database on 4th September 2018 (Reference CRD 42018108946). The searches were performed on the 23rd of August 2018 and repeated on the 30th of August 2018 to ensure accuracy. The Medline search strategy is illustrated in Appendix Table A.1.

Only studies that were published in English were included. Both cases series and comparative studies reporting on surgical interventions for glenohumeral joint degeneration in young patients of any grade were included. For the purposes of this review young patients were defined as patient cohorts all under 65 years or a mean age under 60 years. The study must have reported either functional outcomes, revision rates or survivorship. In addition, only primary research was considered for review with any abstracts, comments, review articles and technique articles excluded. Data from comparative studies and case series were presented together as a narrative synthesis of each individual outcome measure. The robustness of study methodology was appraised using the Methodological index for non-randomised studies (MINORS) [41] and these findings are detailed in Appendix Table A.2.

3. Results

The search strategy identified 30 studies eligible for inclusion (n = 1100);[42–70] 10 HA and glenoid resurfacing (n = 238), 4 HA and glenoid reaming (n = 141), 4 TSA (n = 191), 3 glenoid resurfacing (n = 73), 3 arthroscopic debridement (n = 120), 3 RSA (n = 180), 2 humeral resurfacing (n = 102) and 1 pyrocarbon interposition arthroplasty (n = 55). A flow chart of the search strategy is shown in Appendix Figure A1. Concise details of the included studies are given in Appendices Table A.3 to A.10.

3.1. Hemiarthroplasty and glenoid resurfacing

HA has the potential advantage of avoiding glenoid loosening and failure which is relatively common after TSA in young patients.[25,26] An example case of a 26 year old with post-instability arthropathy treated successfully with hemiarthroplasty is illustrated in Fig. 1A and B. However, HA alone leaves the replacement humeral head articulating with the glenoid which may cause subsequent pain, erosion and arthritis.[21,22, 27–29] This potential glenoid erosion can lead to subsequent problems as revision to an anatomic total shoulder may be compromised by bone loss. This leads to difficult decision making and often the need to consider RSA in a patient who may be still very young and active. The addition of glenoid resurfacing to the HA is an attempt to avoid this metal to bone articulation preventing glenoid pain and erosion thus increasing the longevity of the implant.

Ten studies were identified that reported on results following HA and glenoid resurfacing,[42–51] concise details of these studies are shown in Appendix Table A.3. Within these studies a variety of materials were used for glenoid resurfacing; meniscal allograft, fascia lata, dermal matrix, capsule, achilles allograft or a combination of these.

Overall the post-operative functional outcomes improved following intervention with the mean ASES score ranging from 57.7 to 76 and the mean Constant score from 29 to 58. The largest case series from Lo et al. [47] reported outcomes after dermal matrix resurfacing in 55 patients with a mean age of 50 years. At a mean of 5 years good outcomes were achieved in the majority (mean ASES 76) and the revision rate was 9.1% although only 5.4% for persistent pain believed to originate from the glenoid. However, the remaining 9 studies all reported higher revision rates, ranging from 9.1% to 77%. The highest revision rate was reported by Elhassan et al. who reported at 92% failure rate and 77% revision rate to TSA for persistent pain when their 13 patients were managed with either capsule, fascia lata or achilles allograft for glenoid resurfacing.[50]

Hammond et al.[43] provided the only comparative study comparing HA alone against HA with biological glenoid resurfacing using either a meniscal allograft or dermal matrix. The study reported no statistically significant difference in ASES, Constant score or ROM between the groups but the revision rate was double (60% vs 30%) after glenoid resurfacing. Strauss et al.[48] reported the use of both meniscal allograft (75%) and dermal matrix (25%) and a trend to increased revision rate with dermal matrix (70% vs 45%). Similarly, Puskas et al.[45] presented subgroups according to the material used to resurface the glenoid but the numbers were limited (n = 17) and the failure rate was high in all three groups; dermal matrix 100%, shoulder capsule 67% and meniscal allograft 60%.

3.2. Hemiarthroplasty and glenoid reaming – 'ream and run'

HA and glenoid reaming is another surgical option which avoids a glenoid implant with the associated complications. As an alternative to resurfacing, the glenoid is reamed to ensure that the replaced humeral head can smoothly articulate with the glenoid and might be indicated when version of the glenoid is unacceptable. The downside of this technique is that the important subchondral plate is violated leading to the increased risk of further bone erosion.

Four studies reported results after hemiarthroplasty and reaming of the glenoid,[52–55] details of these studies are given in Appendix Table A.4. Three studies over-reamed the glenoid 2 mm above the

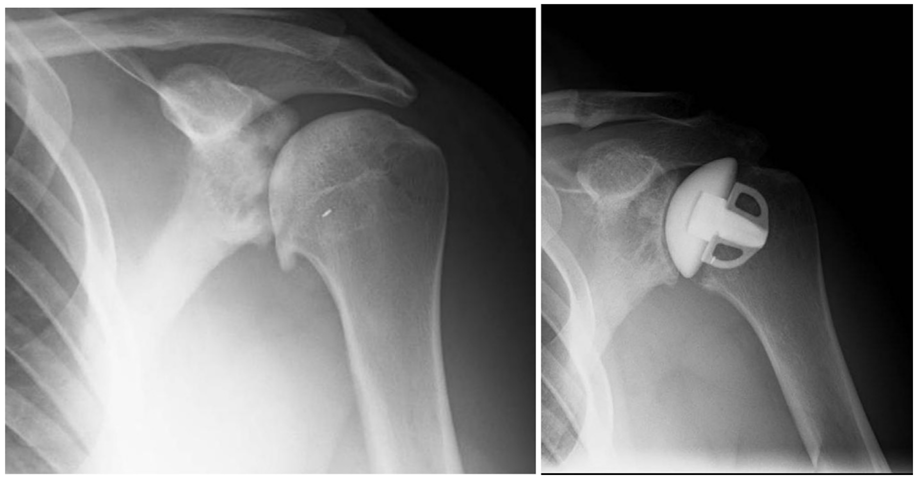

Fig. 1. A and 1B – Pre and Post-operative radiographs of a 26 year old with instability arthropathy treated with stemless hemiarthroplasty and glenoid microfracture.

humeral head size whilst the final study either concentrically reamed or over-reamed by 2 mm. Only one study reported the ASES score with a mean of 90 and three reported the Simple Shoulder Test with post-operative scores ranging from 9.4 to 10. Revision rates varied; Lynch reported that only 2.8% required revision,[55] whereas both Saltzman et al.[52] and Getz et al.[54] reported revision rates for glenoid failure as 10.7% and 16.7% respectively. Although these higher revision rates occurred in populations with lower mean age.

3.3. Total shoulder arthroplasty

TSA has previously been shown to provide better functional results than HA,[30–33] although the long-term risk of glenoid loosening and failure are recognised concerns. Four studies were identified that reported on TSA in young patients,[56–59] study details are presented in Appendix Table A.5. Functional outcomes improved after the surgery with Simple Shoulder Value increasing from 12 to 70 and the Constant Score from 34 to 64.[57,58] Radiographic follow up showed glenoid loosening varied from 17.6% to 43.8% and that subluxation was noted in 50% of cases. The revision rate varied from 6.5% to 34% amongst the studies; Denard et al. and Gauci et al. provided the longest mean follow up for TSA studies.[57,58] Denard et al. reported an overall revision rate of 34% at just under 12 years follow up with the rate of revision for glenoid loosening 24%. Gauci et al. had similar length of follow up and demonstrated a 22% revision rate for all polyethylene cemented glenoid components.

Bartelt provided a comparison of TSA and HA in the management of 46 patients with a mean age of 49 years.[56] At a mean follow up of 7 years, the revision rate was 6.5% for TSA (2.2% for glenoid loosening) and 30% for HA (25% for glenoid pain). Gauci et al. compared results after TSA with cemented polyethylene glenoid and meta-backed glenoid component.[58] The improvement in Constant Score was comparable but at a mean 10 years follow up the revision rate was significantly higher in the metal-backed group; 70% vs 22% ($p < 0.0001$).

3.4. Glenoid resurfacing

Glenoid resurfacing acts an interposition arthroplasty without acquiring the risk of implants in this young population. Numerous materials have been tried as grafts over the years including capsular reflection, free fascia lata, various allograft and xenograft preparations. These techniques rely on having a reasonably smooth and congruent humeral head that articulates with the stable graft. Stabilisation of the graft can be achieved having either with sutures or bone anchors. If the head is arthritic and deformed these procedures have been combined with hemiarthroplasty as previously described.

Three studies reported results after glenoid resurfacing (see Appendix Table A.6) using dermal matrix, meniscal allograft or porcine small intestinal mucosa.[15,60,61] The patients achieved good functional outcomes with ASES score improving to 76–78 and Constant Score of 79. Savoie et al. performed MRI scans on all patients during follow up and demonstrated that 19 of 20 allograft remained intact.[61] In addition, Savoie et al. reported survivorship of 75% at 5 years despite performing the procedure in young population with mean age of 32 years. However, the relatively high revision rates (range 23%–70%) at only midterm follow up raises concerns that the failure rate could rise with longer follow up.

3.5. Arthroscopic debridement

Three studies reported results after arthroscopic treatment,[62–64] detailed in Appendix Table A.7. Both Kerr et al. and Van Thiel et al. groups described arthroscopic debridement with the majority of patients undergoing concomitant procedures which included capsular release, subacromial decompression, biceps tenotomy/tenodesis or distal clavicle resection.[62,64] Millett et al. [63] described a comprehensive arthroscopic management procedure (CAM) which involved glenohumeral chondroplasty, removal of loose bodies, humeral osteoplasty and osteophyte resection, anterior, posterior and inferior capsular release, subacromial decompression, axillary neurolysis and biceps tenodesis for each patient.

Overall all three studies showed good post-operative functional results with ASES score ranging from 72.7 to 83, SANE from 71 to 87 and DASH 17. Revision rates ranged from 15.8% to 22% although the follow up for these arthroscopic studies was even shorter (mean 10–20 months) and the mid to long term results of this approach are not known.

Kerr et al.[62] analysed the relationship between severity of the glenohumeral degeneration and the response to arthroscopic management. The authors reported that the grade of arthritis did not influence functional outcome but the presence of bipolar disease resulted in a poorer prognosis than unipolar disease ($p = 0.014$). Similarly, Millett et al.[63] demonstrated that if the glenohumeral joint distance was under 2 mm that the patient had a 7.8 higher chance of a poor outcome following the CAM procedure ($p = 0.037$).

3.6. Reverse shoulder arthroplasty

RSA has become increasingly used both in the primary arthroplasty setting and as a salvage procedure in the older population but many caution its use in younger patients with long term results in this subgroup still uncertain.[34,35] Three studies reported the results of RSA in young patients and these are presented in Appendix Table A.8.[65–67] The patients included in these studies differed from the other surgical interventions discussed. Overall the mean population age was higher and the prevalence of cuff tear arthropathy higher (59–100%). These significant differences between study population precludes direct comparison of the RSA results to other studies.

The studies report significant improvement in functional scores after RSA with mean post-operative ASES score ranging from 62 to 74 and 81% being satisfied or very satisfied with the outcome. The complication rate ranged from 15% to 37.5% with instability (1.5%–15%) and infection (1.5%–10.5%) the most frequent reasons for revision. Survivorship was reported between 91% and 98% at 5 years and 88% at 10 years follow up.

3.7. Humeral resurfacing hemiarthroplasty

Surface replacement offers a hemiarthroplasty technique but with additional advantages of ease of revision and reduced incidence of periprosthetic fracture. Copeland popularised the technique in the 1990s through to recent times.[71] An example case is illustrated in Fig. 2A, B and 2C where a 26 year old gentleman was managed with humeral resurfacing after a head splitting proximal humeral fracture dislocation with excellent clinical and radiographic results at 17 years follow up. However National joint registries suggest a downturn in its popularity.[72]This has mainly been related to reported early glenoid pain and need for revision.[73–75] The increased popularity of short stem devices also known as “stemless” has encroached on the surface replacement market as these short stems claim to offer the advantages of surface replacement but with the ability to allow better access to the glenoid.

Two studies reported the results after humeral resurfacing in young population,[68,69] see details in Appendix Table A.9. Levy et al.[68] reported on 54 patients either undergoing humeral resurfacing and glenoid microfracture (n = 37) or TSA using a metal-backed glenoid (n = 17). Good functional scores were seen according to the Constant score in both groups with a trend to higher scores after resurfacing (77 vs 58). The revision rate was found to be higher after TSA 29% vs 12% after resurfacing at mean 14.5 years of follow up. 80% of revisions after TSA were due to glenoid loosening, whereas 60% of revisions following resurfacing were due to cuff failure and only one case due to glenoid erosion despite radiographic evidence of erosion in 32% of cases during follow up. Survivorship was similar between resurfacing and TSA at 5 years (97% vs 100%) but by 22 years survivorship was higher after resurfacing 85% vs 61%. Iagulli et al.[69] performed a retrospective case series of 48 patients undergoing resurfacing and at a mean of 6 years follow up reported evidence of radiographic glenoid erosion in 12.5% but that only 2% patients required revision surgery for glenoid pain in the presence of cuff failure. The senior author has observed good clinical long-term outcomes in young patients with resurfacing hemiarthroplasty where the glenoid cartilage was intact at initial surgery (Fig. 1A and B).

3.8. Ceramic and pyrocarbon humeral arthroplasty

Glenoid failure secondary to wear debris and aseptic loosening is a common indication for revision surgery.[76] This is caused by increased eccentric loads, particularly in the case of malalignment, which leads to higher stresses and wear of the polyethylene.[77] Typically the articulating surfaces in shoulder arthroplasty are composed of metallic and polyethylene components. To overcome problem associated with polyethylene wear, alternative bearings have been sought. In total hip replacements, ceramics have been demonstrated to produce lower wear rates than metal heads.[78,79] This favorable wear performance and wide use of ceramics can be attributed to its inertness, low coefficient of friction, wettability, scratch resistance, and reduced hardness.[80] However data for the use of ceramics in shoulder surgery is limited. In a biomechanical study Mueller et al.[81] demonstrated a significant 26.7% reduction in wear when comparing ceramic to metallic heads in anatomic shoulder arthroplasty but further clinical evidence is required to confirm this potential benefit.

Garret et al.[70] performed the only study reporting on pyrocarbon interposition arthroplasty in young patients and details of this study are presented in Appendix Table A.10. Early results at 26.8 months mean follow up showed that Constant scores improved from mean 34 to 66. Radiographic follow up demonstrated glenoid erosion in 10.9% and tuberosity thinning in 5.4%. Survivorship at 4 years was 89% with only one patient (1.8%) requiring revision for persistent pain. The study provides only early outcomes and the authors conclude that until long term results become available that the technique should only be performed at specialist centres.

4. Discussion

The results from this systematic review have highlighted the difficulty managing young active patients presenting with glenohumeral arthritis. Seven different surgical interventions have been presented with each raising concerns regarding revision rates for this subgroup of patients. Failure is especially important in this subgroup given their high activity levels, their longer life expectancy and the challenge presented by revision shoulder arthroplasty given poor glenoid bone stock and deteriorating soft tissues including the deltoid muscle and the rotator cuff.

Both arthroscopic debridement and glenoid resurfacing are techniques that avoid risks of implant failure and may provide a temporising measure to delay need for implant surgery with revision required in 15–22% after arthroscopy and 23–70% after

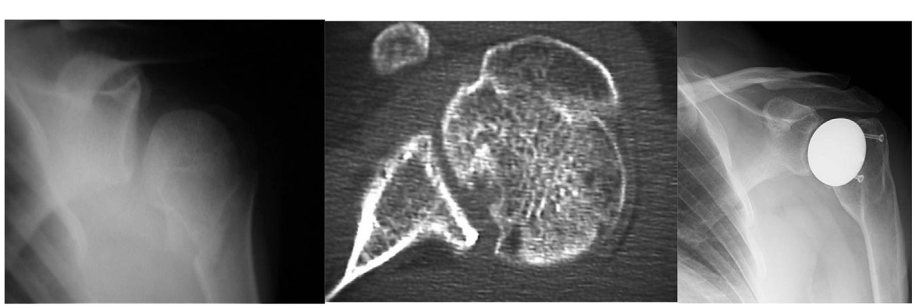

Fig. 2. A, 2B and 2C – Pre-operative, post-operative and 17 year follow-up radiographs of a 26 year old with head splitting proximal humeral fracture dislocation treated successfully with humeral resurfacing and autograft.

glenoid resurfacing. The studies reviewed suggest that if an arthroscopic debridement is considered that patient selection is important with the presence of a well-maintained glenohumeral joint space and unipolar arthritis associated with improved outcomes.[62,63] However, follow up results in these studies was limited to a mean of only 10–20 months. Biological glenoid resurfacing was advocated in young patients to reduce the glenoid erosion and pain after HA, however this technique had globally poor results and this review cannot support its routine use (revision rate 9.1%–77%). The low revision rates reported after humeral resurfacing (2% and 12%) and pyrocarbon interposition arthroplasty (1.8%) are encouraging but the availability of minimal data, the lack of comparative studies and lack of long term follow up prevents strong conclusions being drawn on these modalities.

The 14th UK National Joint Registry (NJR) report states that 4 year revision rates for HA, humeral resurfacing and TSA in England and Wales were 5.01% (3.79–6.59), 5.17% (4.09–6.54) and 3.53% (2.89–4.31) respectively.[72] The revision rates for HA (2.8–25%) and TSA (6.5–34%) in this review were higher that these NJR figures suggesting that this young subgroup of patients are indeed at increased risk of implant failure. The 14th NJR report supports this finding and it reported patients under the age of 65 years are at highest risk of failure with revision rates at 4 years of 7.62% (6.11–9.48) in males and 6.39% (4.9–8.3) in females. However, the NJR data is limited to 4 years follow up, inclusion of 23,608 replacements and further subgroup analysis of younger age groups has not been performed at this stage.[72]

Bartelt et al.[56] did perform a retrospective comparison of TSA and HA and demonstrated a trend to increase revision rate after HA (30% vs 6.4%) but this did not reach statistical significance and the study risked inclusion bias. Similarly the higher revision rates reported after TSA, 22% and 34%, were reported at 124 months and 115 months, whereas comparable revision rates after HA were reported over a shorter follow up period (32–51 months) suggesting TSA may have a comparably lower failure rate. The results from Gauci et al.[58] did demonstrated that meta-back glenoid components had a higher risk of failure that all polyethylene implants in TSA. Possible explanations for this include over lateralisation risking soft tissue failure,[82,83] difference in elasticity between metal and bone increasing risk of stress shielding [84–86] and difference in elasticity between polyethylene and metal increasing risk polyethylene wear.[87,88]

Although three studies were identified that reported on RSA in young patients, most patients included in these were reported to have cuff tear arthropathy and thus provided a different cohort of patients to those receiving the other interventions where post-instability, post-surgical, post-traumatic and primary osteoarthritis were the most frequent indication. These studies did show RSA is an option for these young patients with cuff arthropathy, but long-term studies are still required to test the implants survivorship in this young patient population with previous studies suggesting radiographic results, functional outcomes and survivorship deteriorated at a follow-up time of six to eight years after RSA.[35]

Appraisal of the studies using the Methodological index for non-randomised studies (MINORS) tool demonstrated a variety of limitations which are summarised in Appendix Table A.2. One major limitation of this review is its failure to identify all surgical interventions for treating glenohumeral degeneration in young patients despite the purposefully broad inclusion criteria. Cell therapy in the form of osteochondral autologous transfer surgery [13] and autologous chondrocyte implantation [14] has been proposed but data is limited to case reports and small case series. The use of partial prosthetic resurfacing such as the HemiCAP device (Arthrosurface Inc., Franklin, MA, USA) has been proposed as an option for contained defects in the humeral head with Sweet et al. reporting 20 cases with mean age of 48.9 years, good functional improvement ASES score 24.1 to 78.8 and 10% revision rate.[89]

Wang et al. reported an overall survival rate of 76.6% at 9.6 years after microfracture in 13 shoulders with a mean age of 36 years.[16] Similarly, Millet et al. reported on 31 cases with 4 years follow up with improvement in pain and function for small, focal isolated lesions on humeral head but poorer outcomes with bipolar lesions.[17]

5. Conclusion

Surgical intervention in young patients with glenohumeral degeneration carries higher risk of failure and subsequent need for potentially complex revision surgery. Therefore non-operative measures should be exhausted and patients adequately counselled prior to proceeding to arthroplasty. Although humeral resurfacing, HA and TSA have been shown to produce functional improvements, secondary to its lower revision rates and previous comparative studies demonstrating improved functional outcomes, TSA is proposed as the optimal treatment when arthroplasty is considered in these patients. Pre-operative planning with 3D simulation, patient specific guides and navigation techniques are now being used by surgeons to better recreate normal anatomy and orientation of implants. New materials such as Vitamin E enriched polyethylene and ceramic humeral heads may reduce particulate wear and thus the longevity of the bearing surfaces in younger patients however the outcomes of such innovations are as yet unknown.

Conflicts of interest

No funding was received during the production of this manuscript.

Mr RW Jordan is currently undertaking a shoulder fellowship funded by Mathys (UK)

Mr CP Kelly is part of the development team for the Mathys Stemless implant.

Appendix

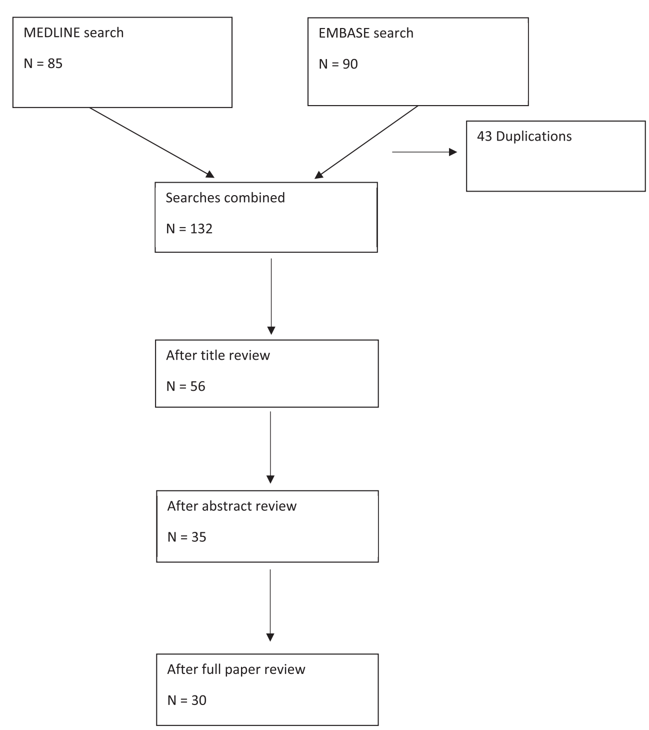

Fig. AI. Flow diagram of review process.

Table A.1
Search strategy for Medline

Search number	Search term	Number
1	Shoulder arthritis.mp.	91
2	SHOULDER JOINT/	17553
3	ARTHRITIS/	34431
4	2 and 3	500
5	Glenohumeral arthritis.mp.	242
6	Young patient.mp.	4508
7	Young patients.mp.	18526
8	YOUNG ADULT/or young.mp.	1004177
9	1 or 4 or 5	732
10	6 or 7 or 8	1004177
11	9 AND 10	85

Table A.2
Methodological items for non-randomised studies (MINORS) Scores for included studies

	Clear aim	Includes consecutive patients	Appropriate endpoints	Unbiased assessment	Appropriate follow-up	Loss to follow up <5%	Prospective study size calculation	Additional criteria if comparative study	Adequate control group	Contemporary groups	Baseline groups equivalent	Adequate statistical analyses	Total Score
Burkead et al.[42]	1	0	2	0	2	1	0	N/A	N/A	N/A	N/A	0	6/16
Hammond et al.[43]	2	2	2	2	2	1	0	1	2	2	2	2	20/24
Muh et al.[44]	2	0	2	0	2	2	0	N/A	N/A	N/A	N/A	2	10/16
Puskas et al.[45]	2	0	2	0	2	2	0	N/A	N/A	N/A	N/A	1	9/16
Lee et al.[46]	2	0	2	0	2	2	0	N/A	N/A	N/A	N/A	0	8/16
Lo et al.[47]													
Strauss et al.[48]	2	0	2	2	2	1	0	N/A	N/A	N/A	N/A	2	11/16
Bois et al.[49]	2	0	2	2	2	1	1	N/A	N/A	N/A	N/A	2	12/16
Elhassan et al.[50]	2	1	2	0	1	2	0	N/A	N/A	N/A	N/A	2	10/16
Wirth et al.[51]	2	2	2	0	2	1	0	N/A	N/A	N/A	N/A	2	11/16
Saltzman et al.[52]	2	2	2	0	2	1	0	N/A	N/A	N/A	N/A	2	11/16
	Clear aim	N/A	Appropriate endpoints	Unbiased assessment	Appropriate follow-up	Loss to follow up <5%	Prospective study size calculation	Additional criteria if comparative study	Adequate control group	Contemporary groups	Baseline groups equivalent	Adequate statistical analyses	Total Score
Somerson et al.[53]	2	2	2	0	2	1	0	N/A	N/A	N/A	N/A	2	11/16
Getz et al.[54]	2	1	2	1	2	1	0	N/A	N/A	N/A	N/A	2	11/16
Lynch et al.[55]	2	2	2	1	2	1	0	N/A	N/A	N/A	N/A	2	12/16
Bartelt et al.[56]	2	2	2	0	2	2	0	1	2	2	1	2	18/24
Denard et al.[57]	2	0	2	2	2	2	0	N/A	N/A	N/A	N/A	2	12/16
Gauci et al.[58]	2	2	2	0	2	2	0	1	2	2	2	2	19/24
Kusnezov et al.[59]	2	2	2	0	1	0	0	N/A	N/A	N/A	N/A	2	9/16
Hartzler et al.[60]	2	2	2	0	2	1	0	N/A	N/A	N/A	N/A	2	11/16
Savoie et al.[61]	2	1	2	0	2	1	0	N/A	N/A	N/A	N/A	1	9/16
Kerr et al.[62]	1	1	2	0	1	2	0	N/A	N/A	N/A	N/A	2	9/16
Millett et al.[63]	2	2	2	0	1	1	0	N/A	N/A	N/A	N/A	2	10/16
	Clear aim	Includes consecutive patients	Appropriate endpoints	Unbiased assessment	Appropriate follow-up	Loss to follow up <5%	Prospective study size calculation	Additional criteria if comparative study	Adequate control group	Contemporary groups	Baseline groups equivalent	Adequate statistical analyses	Total Score
Van Thiel et al.[64]	2	1	2	2	1	1	0	N/A	N/A	N/A	N/A	2	11/16
Ek et al.[65]	2	2	2	0	2	2	0	N/A	N/A	N/A	N/A	2	12/16
Samuelson et al.[66]	2	0	2	0	2	2	0	N/A	N/A	N/A	N/A	2	10/16
Muh et al.[67]	2	0	2	0	2	1	0	N/A	N/A	N/A	N/A	2	9/16
Levy et al.[68]	2	2	2	0	2	1	0	1	1	1	1	2	15/24
Iagulli et al.[69]	2	2	2	0	2	1	0	N/A	N/A	N/A	N/A	2	11/16
Garrett et al.[70]	2	2	2	1	2	2	0	N/A	N/A	N/A	N/A	2	13/16

MINOR scores: 0 (not reported), 1 (reported but inadequate) and 2 (reported and adequate).

Table A.3
Summary of studies reporting hemiarthroplasty with biologic glenoid resurfacing

Study	Population	Intervention (s)	Comparator	Follow up (months)	Outcome Measures	Results	Revisions
Burkead et al. [42] (n = 6)	Mean 48 yrs[33–54] 100% male	Uncemented porous-coated modular HA Fascia lata autograft for glenoid	None	Mean 28[24–34]	ROM Neer rating scale Pain	ROM • FF 81 to 138 • ER 5 to 50 • IR from L5 to T12 Neer rating scale • 83.3% excellent • 16.7% satisfactory results 83.3% excellent pain relief	16.7% revision rate Biceps tenodesis
Hammond et al. [43] (n = 20)	Mean 37.7 yrs[19–54]	BR group Cemented or cementless stemmed HA (n = 20) Lateral meniscal allograft or dermal matrix for glenoid	HA group Cemented or cementless stemmed HA (n = 21)	Mean 44.4 (12–88.8)	ASES Constant SST SANE VAS pain Radiographs ROM	ASES • BR group 59.5 • HA group 67 Constant • BR group 53 • HA group 67.9 SST • BR group 6.9 • HA group 7.5 VAS • BR group 4.8 • HA group 1.8 HA better VAS ($p < 0.05$) No difference SST, ASES, Constant or ROM	BR group • 60% revision rate • 0% glenoid erosion HA group • 30% revision rate 58% glenoid erosion on radiographs
Muh et al. [44] (n = 16)	Mean 36.1 yrs[14–45] 75% men	Stemmed HA or resurfacing Glenoid dermal matrix or achilles allograft	None	Mean 60 (24–96)	ASES VAS pain ROM	ASES 23.2 to 57,7 ($p < 0.05$) VAS 8.1 to 5.8 ($p < 0.05$)	44% revision rate • Mean 36 months • 100% converted to TSA Converted to TSA
Puskas et al. [45] (n = 17)	Mean 43 yrs[31–57]	Stemmed HA or resurfacing Glenoid • Dermal matrix (n = 6) • Meniscal allograft (n = 5) • Capsule interposition(n = 6)	None		SSV Constant score VAS pain ROM	SSV • Dermal matrix 23 to 35 • Meniscus 22 to 50 • Capsule 32 to 46 Constant score • Dermal matrix 32 to 29 • Meniscus 40 to 51 • Capsule 43 to 58 VAS Pain • Dermal matrix 4 to 7 • Meniscus 6 to 7 • Capsule 6 to 7	Dermal matrix • 100% failure • 83% revision rate • Mean 16 months Meniscus allograft • 60% failure • 60% revised • Mean 22 months Capsule interposition • 67% failure • 67% revised Mean 34 months
Lee et al. [46] (n = 21)	Mean age 54.8[35–68] 71% men	Humeral resurfacing Capsule used for glenoid resurfacing	None	Mean 57.6 (24–127.2)	Constant score ASES Shoulder assessment form VAS Pain ROM Radiographs	Constant score 71.4 (41–95) ASES 74.4 (35–100) VAS pain at rest 0.5 (0–3) 56% moderate to severe glenoid erosion	14.2% revision rate • 4.7% converted to TSA for pain at 15 months • 4.7% infection 4.7% impingement
Lo et al. [47] (n = 55)	Mean 50 yrs[23–65]	Cemented stemmed humeral component Dermal matrix for glenoid	None	Mean 60 (26–109)	WOOS ASES Pain SANE	WOOS 448±423 ASES 76±22 VAS pain 2.4±2.6	9.1% revision rate • 5.4% persistent pain • 1.8% Infection o 1.8% intraop humeral fracture Further 11% had poor function
Strauss et al. [48] (n = 41)	Mean 42.2 yrs (18–60)	Stemmed HA 84% and 16% resurfacing Lateral meniscal allograft (75%) or dermal matrix (25%) for glenoid	None	Mean 33.6 (8–98)	ASES SST Pain VAS	ASES 36.8 to 62 ($p < 0.05$) SST 4 to 7 ($p < 0.05$) VAS 6.3 to 3 ($p < 0.05$)	Clinical failure • Mensicus 45% • Dermal matrix 70% Revision rate 19.% to TSA
Bois et al. [49] (n = 22)	Mean 46 yrs[27–55] 69% men	Stemmed HA Meniscal allograft for glenoid resurfacing	None	Mean 99.6 (60–120)	ASES SST VAS pain Radiographs ROM	ASES 31.6 to 59.6 ($p < 0.001$) SST 2.8 to 6.3 ($o < 0.001$) GH joint space 3.6 mm –1.4 mm Increased posterior glenoid erosion 2.8 mm to 4.1 mm	10 year survivorship 56.3% 30% known revisions 9 complications • 3 post op infections • 6 persistent shoulder pain and stiffness
Elhassen et al. [50] (n = 13)	Mean 34 yrs[18–49] 69% men	Stemmed anatomic prosthesis Glenoid resurfaced using capsule, fascia	None	Mean 48 (6–102)	SSV Constant score VAS pain	SSV 21 to 33 Constant score 24 to 43 VAS pain 8 to 6	92% failure rate Revisions • 10 revision to TSA, mean time 16 months • Capsular release 4

(*continued on next page*)

Table A.3 (*continued*)

Study	Population	Intervention (s)	Comparator	Follow up (months)	Outcome Measures	Results	Revisions
		lata or achilles allograft					• Irrigation and debridement 1 Resection arthroplasty 1
Wirth et al. [51] (n = 27)	Mean 43[24–53] 70% men	Stemmed anatomic prosthesis Meniscal allograft for glenoid	None	Mean 36[24–60]	ASES SSV ROM	SST 2.7 to 7.3 ASES 30 to 67	11% Revision rate • Displaced graft converted to shoulder replacement • 2 TSA for pain 7.4% infection rate

Abbreviations: ROM – range of motion, FF – forward flexion, ER – external rotation, IR – internal rotation, BR – biologic rotation, HA - hemiarthroplasty, ASES – American Shoulder Elbow Surgeons score, SST – Simple Shoulder Test, SANE - Single Assessment Numerical Evaluation score, VAS – Visual analogue score, TSA – total shoulder arthroplasty, WOOS - West Ontario Osteoarthritis Score, SSV – Subjective Shoulder Value, GH – Glenohumeral.

Table A.4
Summary of studies reporting hemiarthroplasty with glenoid reaming

Study	Population	Intervention (s)	Follow up	Outcome Measures	Results	Revisions
Saltzman et al. [52] (n = 65)	Mean 48 yrs[22–55] 90.7% men	Stemmed humeral component Glenoid over reamed by 2 mm	Mean 43[24–85]	SST Radiographs	SST 4.1 to 9.5 ($p = 0.001$) 72.7% of radiographs centred	Revision rate 13.8% • 4 to TSA • 2 repeat glenoid reaming • 1 to reverse • 1 infection • 1 bone impingement
Somerson et al. [53] (n = 17)	Mean 55 yrs[24–69] 64.7% men	Stemmed humeral component Glenoid over reamed by 2 mm	Median 51.6 (24–81.6)	SST ASES ROM Radiographs	SST 3.9 to 10.0 ($p < 0.0001$) ASES 43 to 90 ($p < 0.0001$)	Revision rate 17.6% • Mean 32 months • 2 instability • 1 residual pain
Getz et al. [54] (n = 24)	Mean 50 yrs (32–62.3) 100% men B2 Glenoids	Stemmed humeral component 54% Concentric glenoid reaming 46% 2 mm over-reamed	Mean 32.4 (8–110.4)	SST score PSS (with <70 defined as poor result) Revision rate Radiographs	42% had fair or poor outcome PSS 21% had residual posterior subluxation	Revision rate 25% • 66.7% persistent pain at mean 11 months
Lynch et al. [55] (n = 35)	Mean 57 yrs[35–80] 91% men	Stemmed humeral component Glenoid over reamed by 2 mm	Mean 32.4[24–48]	SST Revision rate	SST 4.74 to 9.4	Revision rate 2.8% • Repeat reaming

Abbreviations: SST – Simple Shoulder Test, TSA – Total Shoulder Arthroplasty, ASES – American Shoulder and Elbow Surgeons score, ROM – range of motion, PSS – Penn Shoulder Score.

Table A.5
Summary of studies reporting total shoulder arthroplasty

Study	Population	Intervention (s)	Comparator	Follow up	Outcome Measures	Results	Complications
Bartelt et al. [56] (n = 46)	Primary or secondary OA Mean 49 yrs[21–55] 67% men	TSA 4% required cuff repair	HA Mean age 49 yrs[26–55] 80% men	Mean 84 (9–242)	Pain Radiographs Neer Pain – 0 to 5	Pain TSA 4.4 to 2 HA 4.5 to 2.9 Subluxation 50% TSA 53.8% HA 17.6% TSA glenoid lucency	Revisions TSA 6.5% • 4.3% infection • 2.2% glenoid loosening HA 30% • 25% for pain (mean 4.5 years) • 5% infection TSA Survival • 100% at 5 years • 92% at 10 years HA Survival • 85% at 5 years • 72% at 10 years
Denard et al. [57] (n = 50)	Mean 50.5 yrs[35–55]	TSA with keeled glenoid. 92% humerus cemented (Aequalis; Tornier, Edina, MN, USA)	None	Mean 115 (60–211)	Constant score SSV Radiographs	Constant score 31.6 to 20.7 ($p < 0.001$) SSV 12 to 70 Radiographic loosening 43.8%	Survivorship of glenoid • 98% 5 year • 62% at 10 years 34% revision • 24% due to glenoid loosening • 4% subscapularis rupture • 2% humeral loosening • 2% oversized humeral head
Gauci et al. [58] (n = 69)	Cemented group Mean 55 yrs[40–60] Metal-backed group Mean 53 yrs[35–60]	Cemented anatomic shoulder replacement, trapezoidal glenoid keel (Aequalis PE; Tornier,	Anatomic shoulder replacement, metal-backed glenoid (Aequalis MB	Mean 124 months	Constant scores SSV VAS for pain Radiographs	Constant score • Cemented PE 33 to 64 • Metal–backed 36 to 64 SSV • Cemented 69 • Metal-backed 71	Survivorship at 12 years • 74% for cemented PE • 24% for metal-backed • $P = 0.00002$ Revision 70% vs 22% ($p < 0.0001$)

Table A.5 (*continued*)

Study	Population	Intervention (s)	Comparator	Follow up	Outcome Measures	Results	Complications
		Montbonnot, France) N = 46	Glenoid; Tornier, Montbonnot, France) N = 23			VAS pain • Cemented 3 • Metal-backed 4	Complications • 28.2% cemented • 91% metal-backed
Kusnezov et al. [59] (n = 26)	Post-instability 50% Post-traumatic OA 26.9% Primary OA 19.2% Mean 45.8 yrs[35–54] 96% men	Anatomical TSR	None	Mean 41 (11.6 −97.6)	Pain Return to duty ROM	Pain • 5.2 to 1.4 Return to duty • 72% at 1 year • 45.5% at two years	35% complications • 23.1% component failures • 7.7% glenoid acute failures after dislocations • 11.5% glenoid loosening • 3.8% humeral loosening

Abbreviations: OA - osteoarthritis, TSA – total shoulder arthroplasty, HA - hemiarthroplasty, SSV – Simple Shoulder Value, PE - polyethylene, VAS – Visual Analogue Score, ROM – range of motion.

Table A.6
Summary of studies reporting glenoid resurfacing

Study	Population	Intervention (s)	Follow up	Outcome Measures	Results	Revisions
Hartzler et al. (n = 43) [60]	Mean 57 yrs[55–59]	Dermal allograft >2 mm Graft Jacket	45 months[9–71]	ROM VAS pain ASES SSV Radiographic	• VAS 7 (6–8) to 2 (1–4) • ASES 47 (35–55) to 76 (57–88) • SSV post op 73 (65–90)	23.2% revision rate • 3 HA • 4 TSA • 3 RSA
Karelse et al. [15] (n = 10) RCT	Mean 44 yrs (19–57) 60% men	Meniscal allograft or dermal allograft	24	Constant score VAS	Constant score • 34 (15–46) VAS • 29 (28–33)	70% revision rate
Savoie et al. [61] (n = 20)	Mean 32 yrs (15–58)	Porcine small intestine mucosa	36–72	ASES UCLA Rowe score Constant-Murley VAS pain MRI	• Mean ASES 22 to 78 • UCLA 15 to 29 • Rowe score 55 to 81 • Constant-Murley score 26 to 79 • VAS pain 8 (0–10) to 2 • MRI 19/20 allograft intact	25% revision at 5 years

Abbreviations: ROM – range of motion, VAS – Visual Analogue Score, ASES – American Shoulder and Elbow Surgeons score, SSV – Subjective Shoulder Value, HA - hemiarthroplasty, TSA – total shoulder arthroplasty, RSA – reverse shoulder arthroplasty, RCT – randomised controlled trial, UCLA – University of California at Los Angeles Shoulder Score.

Table A.7
Summary of studies reporting arthroscopic treatment

Study	Population	Intervention (s)	Follow up (months)	Outcome Measures	Results	Revisions
Kerr et al. [62] (n = 19)	Mean age 38 (20–54) 63% men RC intact	Arthroscopic debridement	Mean 20[12–33]	WOOS ASES SANE score SF-12	• WOOS 0.64 (0.12–0.98) • ASES 75.3 (24–100) • SANE score 71% • Comparable between grade 2/3 and grade 4 • Bipolar performed worse than unipolar o WOOS 0.52 vs 0.89 (p = 0.014) o SANE 49.3 to 89.6 (p = 0.022)	15.8% TSA
Millett et al. [63] (n = 30)	Mean age 52 (33–68) 79% men	Comprehensive arthroscopic management procedure	Mean 19.2 (25.2–56.4)	ROM ASES DASH SANE score Survivorship	ROM • FF 98.2 (20–180) to 152 (90–180) • ER 13.4 (−15 to 80) to 75.4 (45–100) ASES • 58 (42–78) to 83 (60–100) DASH • Post-op 17 (0–41) SANE score • 87 (70–100)	20% revision to replacement Survivorship • 92% 1 year • 85% 2 years Patients <2 mm GH joint space 7.8 times more likely to revise (p = 0.037)
Van Thiel et al. [64] (n = 71)	Mean age 47 (18–77) 66% men RC intact		Mean 10.1 (2.5–27.2)	Revision SST ASES SF-12 VAS pain ROM UCLA SANE	• WOOS 0.64 (0.12–0.98) • SST 6.1 (0–12) to 9[3–12] • ASES 51.8[8–85] to 72,7 (10–100) • VAS pain 4.8 (1–9) to 2.7 (0–9) • UCLA Post 28.3 (16–25) • SANE 71.1 (5–100)	Failure 22% • 4 HA • 9 TSA • 3 humeral head allograft

Abbreviations: RC - rotator cuff, WOOS - West Ontario Osteoarthritis Score, ASES – American Shoulder and Elbow Surgeons score, SANE – Single Assessment Numerical Evaluation score, SF-12 – Short Form survery, TSA - total shoulder arthroplasty, ROM – range of motion, DASH – Disabilities of the Arm, Shoulder and Hand score, GH – glenohumeral, SST -Simple Shoulder Test, VAS- Visual Analogue Score, UCLA – University of California at Los Angeles Shoulder score, HA – hemiarthroplasty.

Table A.8
Summary of studies reporting reverse shoulder arthroplasty

Study	Population	Intervention (s)	Follow up	Outcome Measures	Results	Complications
Ek et al.[65] (n = 46)	Massive cuff tears Mean 60 yrs[46–64] 58% men	80% Delta III reverse (DePuy, Saint-Priest, France) 20% Anatomical Shoulder Reverse (Zimmer, Winterthur, Switzerland)	Mean 93 (60–171)	Constant score SSV ROM Radiographs	Constant 34 to 74 ($p < 0.0001$) SSV 23 to 66 ($p < 0.0001$) Notching in 56% of cases • Stage 1 24% • Stage 2 9% • Stage 3 21% • Stage 4 3%	Survival analysis • 98% at 5 years • 88% at 10 years 37.5% complications • 15% instability • 10.8% infection • 6.5% glenoid loosening
Samuelsen et al. [66] (n = 67)	CTA 76% 22% OA Mean 60 yrs[50–65] 59.7% men	Four RSA implants 59.7% uncemented	Mean 36 (24–96)	ASES SST Pain 1 to 5 ROM Radiographs	ASES 62±16 SST 5.9±3 Radiographs • 18% notching • 3% glenoid lucency	3% revision rates • 1.5% Infection • 1.5% Instability Survivorship • 99% at 2 years • 91% at 5 years
Muh et al. [67] (n = 67)	CTA 59.7% Failed primary 13.4% Inflammatory 14.9% Post traumatic 6% Mean 52.2 yrs[23–60] 37/66 men	Grammont design reverse shoulder prosthesis (Tornier, Saint-Ismier, France	Mean 36.5[24–77]	ASES VAS pain score ROM Radiographs	ASES 40 to 72.4 VAS pain 7.5 to 3.0 81% patients were either very satisfied or satisfied Scapula notching 43% • Grade 1 32.8% • Grade 2 7,5% • Grade 3 3%	15% Complications • 7.4% instability, 3% required revision • 4.5% infections • 1.5% Humeral fracture • 1.5% nerve palsy

Abbreviations: SSV – subjective shoulder value, ROM – range of motion, HA - hemiarthroplasty, CTA – cuff tear arthropathy, OA - osteoarthritis, RSA – reverse shoulder arthroplasty, ASES – American Shoulder and Elbow Surgeons score, SST – Simple Shoulder Test, VAS – Visual Analogue Score.

Table A.9
Summary of studies reporting humeral resurfacing

Study	Population	Intervention (s)	Comparator	Follow up	Outcome Measures	Results	Complications
Levy et al. [68] (n = 54)	Mean 38.9[22–50] 51% men	Copeland resurfacing (Biomet, Swindon, UK) Microfracture of glenoid	TSA with metal-backed glenoid	Mean 174 (120–300)	Constant score SANE Radiographs	Constant • HA 77 • TSA 58.1 ROM • HA FF 78 to 116 • HA abduction 55 to 108 • TSA FF 42 to 93 • TSA Abduction 38 to 81 Radiographs • 58% superior migration • 32% HA glenoid erosion	Revisions 5 TSA • Four loosening • 1 cuff failure 5 HA • 3 cuff failure • 1 glenoid erosion • 1 fracture Overall survivorship HA • 97% at 5 years • 97% at 10 years • 91% at 14 years • 85% at 22 years TSR • 100% at 5 years • 71% at 11 years • 71% at 14 years • 61% at 22 years
Iagulli et al. [69] (n = 48)	Mean 48 yrs[21–59]	Humeral resurfacing - Biomet Copeland prosthesis n = 22 (Warsaw, Indiana, USA). DePuy Global Cap n = 26 (Raynham, Massachusetts, USA)		Mean 72 (48–96)	UCLA score Satisfaction level Radiographs	VAS pain 7 to 1 UCLA 12.24 to 28.12 12.5% glenoid erosion	2% revision rate due to ongoing pain and cuff failure

Abbreviations: TSA – total shoulder arthroplasty, SANE - Single Assessment Numerical Evaluation score, HA - hemiarthroplasty, TSA – total shoulder arthroplasty, FF – forward flexion, UCLA – University California in Los Angeles score, VAS – Visual Analogue Score.

Table A.10
Summary of studies reporting pyrocarbon interposition arthroplasty

Study	Population	Intervention (s)	Follow up	Outcome Measures	Results	Complications
Garret et al. [70] (n = 55)	Mean 50.7 (18–77) 50.7% men	Pyrocarbon arthroplasty - Inspyre implant (Tornier SAS, Montbonnot Saint Martin, France)	Mean 26.8 (24–38)	Constant score	Constant score 34.1 to 66.1 Radiographs • 10.9% Glenoid erosion • 5.4% Tuberosity thinning • 16.4% Humeral medialisation	Implant survival 89.2% at 49.7 months Complications • 3.6% Posterior subluxation • 3.6% Impingement • 3.6% Cuff tears • 1.8% Persistent glenoid pain requiring revision

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