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Porous metal wedge augments to address glenoid retroversion in anatomic shoulder arthroplasty: midterm update

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Background: Wedge-shaped porous metal augments were used to address bone deficiency in shoulder arthroplasty as part of a hybrid combination of high-density polyethylene, polymethyl methacrylate bone cement, and porous metal implant. This article presents an ongoing review of the use of the generically designed augments in the shoulder to address glenoid retroversion as part of anatomic total shoulder arthroplasty (aTSA).

Materials: Seventy-five shoulders in 66 patients (23 women and 43 men, aged 42-85 years) with Walch grade B2 or C glenoids underwent porous metal glenoid augment (PMGA) insertion as part of aTSA. Patients underwent preoperative 3-dimensional (3D) templating; based on that planning, patients received either a 15° or 30° PMGA wedge (secured by screws to the native glenoid) to correct excessive glenoid retroversion before a standard glenoid component was implanted using bone cement. Neither patient-specific guides nor navigation were used. Intraoperative glenoid alignment was assessed using a reusable guide that referenced the anterior scapular neck. Patients were prospectively assessed using shoulder functional assessments (Oxford Shoulder Score [OSS], American Shoulder and Elbow Surgeons Standardized Shoulder Assessment Form [ASES], visual analog scale [VAS] pain scores, and forward elevation [FE]) preoperatively; at 3, 6, and 12 months postoperation; and yearly thereafter, with similar radiologic surveillance.

Results: Of the total consecutive series, 49 shoulders had a follow-up of greater than 24 months, with a median follow-up of 48 months (range: 24-87 months). For this cohort, median outcome scores improved for OSS (21 to 44), ASES (24 to 92), VAS (7 to 0), and FE (90° to 140°) from preoperative outcomes to the most recent review, respectively. Four patients died, but no others were lost to follow-up. Apart from 1 infection at 18 months postoperatively and 1 minor peg perforation, there were no complications, hardware failures, implant displacements, significant lucency, or posterior resubluxations. Radiographs showed good incorporation of the wedge augment, with correction of glenoid retroversion from median 22° (13° to 46°) to 4° (17° to anteversion 16°). All but 4 glenoids were corrected to within the target range (less than 10° retroversion), and only 2 glenoid components were implanted outside 15° of neutral glenoid version.

Conclusions: The porous metal wedge–shaped augments effectively addressed posterior glenoid deficiency as part of aTSA for rotator cuff intact osteoarthritis, producing satisfactory clinical outcomes with no signs of impending future failure.

Level of evidence: Level IV; Case Series; Treatment Study

Keywords: B2 glenoid; retroversion; shoulder arthroplasty; porous metal; wedge augment; osteoarthritis

The trial to review the outcomes of the implants was endorsed by the Royal Adelaide Hospital and St Andrews Hospital Human Research Ethics Committees and conducted under the Authorized Prescriber provisions of the Australian Government Department of Health Therapeutic Goods Administration (Trabecular Metal Glenoid Augment: Authorized Prescriber: 2012/022).

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Management of the degenerate retroverted glenoid is challenging and controversial.[21] Mehta and Aleen[22] recently published a detailed overview titled ''Management of the B2 Glenoid in Glenohumeral Arthritis,'' in which they highlighted the multiple management options and recommended that surgeons use ''patient-specific factors to guide their therapeutic choices.''

According to their study, when performing a shoulder arthroplasty for a patient with a B2- or C-shaped arthritic glenoid, there are essentially 2 choices: either anatomic or reverse replacement.[21,22] If an anatomic replacement is selected (either total arthroplasty or hemiarthroplasty), the approach involves either accepting the original version or attempting to change the glenoid alignment toward neutral.

If changing the version toward neutral, the anterior glenoid can be lowered or the posterior articulating surface raised. Eccentric anterior glenoid reaming has a limited capacity to address retroversion,[6,19,35] but is regularly used for mild malalignment. For more severe corrections, the back must be raised, to achieve which there are again 2 broad choices: use a bone graft[12,22,24] or use an eccentrically shaped glenoid implant.[9,19,20,22] If a nonstandard glenoid component or combination is selected, the surface interfacing the native glenoid presents essentially 3 shape choices: wedged,[26,29,36] stepped,[9,17,19] or irregular.[20] The glenoid component can be attached to the native bony glenoid as cemented high-density polyethylene (HDPE),[36] porous ingrowth metal,[29] or a combination of both, with or without screws.[22]

Porous metal implants have a long history of successfully correcting bone deficiencies in lower limb arthroplasty,[7,8,13] suggesting that ingrowth and long-term stabilization of such an implant, even on an angled surface, can be anticipated.[8] Such devices appear to possess the advantages of bone grafts in terms of their ability to correct substantial degrees of bone deficiency while also avoiding the downsides of the biological option, which include the technical challenges of preparing and stabilizing a graft, and longer-term failure due to the collapse of the graft.[12]

We have previously presented the short-term results of using a wedge-shaped porous metal implant, which acts much like a bone graft, to address deficiencies of the posterior glenoid.[29]

The purpose of this article is not to compare or debate the multiple options for addressing retroverted degenerate glenoids but to highlight the potential theoretical advantages of a wedge-shaped porous metal augment combined with a cemented conventional glenoid component, and to present the midterm clinical outcomes in a consecutive clinical series.

The hypothesis was that by adopting a solution based on strong theoretical and wider clinical evidence, a satisfactory outcome could be achieved with anatomic arthroplasty for arthritic retroverted glenoids.

A further aim of this article was to review the options for presenting the clinical data and assess which would provide the most informative means to portray the outcomes, particularly with regard to the likely occurrence of skewed data secondary to ceiling and basement effects.[34]

Materials and methods

This study was conducted as a prospective open-label cohort study of patients undergoing anatomic total shoulder replacement who presented with an arthritic retroverted glenoid greater than 15° with an intact rotator cuff. All surgery was performed by the senior author (M.S.).

Inclusion criteria, outcomes analysis, and the surgical technique for performing the glenoid replacement as a hybrid combination of HDPE, polymethyl methacrylate bone cement, and a porous metal glenoid augment (PMGA) were consistent with the previous report.[29] Because of subsequent issues regarding implant availability, wedges made of 3D-printed titanium alloy (Signature Orthopaedics [Australia], Sydney, Australia; and Signature Orthopaedics [USA], Bartlett, TN, USA) with the same geometric specifications as previous implants were used in more recent patients. The change in supplier and material was accepted by the ethics committee and regulator after detailed review and consideration of available published information,[5] as they considered the alternate device sufficiently similar to constitute a like-for-like substitution.

As detailed in the initial report,[29] the metal augments had a pore size of approximately 500 μm. The curved surfaces matched the back (glenoid facing) surface of the Bigliani-Flatow (Zimmer-Biomet, Warsaw, IN, USA) glenoid component and were divergent by either 15° or 30°. The anterior margin of the augment was slightly truncated to allow the anterior edge of the glenoid component to rest on native glenoid. The augments contained holes to accommodate the central pegs of the glenoid component, in addition to the holes for the initial stabilizing screws (Fig. 1).

Consistent with the previous report,[29] outcome scores, including the American Shoulder and Elbow Surgeons Standardized Shoulder Assessment Form (ASES) score,[27] Oxford Shoulder Score (OSS),[25] visual analog scale for pain, and range of forward elevation, were taken preoperatively; at 3, 6, and 12 months postoperation; and yearly thereafter, with regular radiologic review depending on clinical circumstances. The intention was—and remains—to follow patients until deceased. The patients were also followed as part of the Australian Orthopaedic Association Joint Replacement Registry; episodic ad hoc analysis provided independent validation of implant retention results.[4] Follow-ups were regarded to have occurred at a specific designated time point if the follow-up review occurred within 5% of the months postoperatively of that actual time point.

Preoperative radiologic analysis and preoperative planning

Preoperative plain radiographs and computed tomography (CT) scans were performed on all patients. The CT scan data were then used to create a 3D virtual model of the patient's shoulder, and, using specially designed graphics software (VPOPS [Virtual

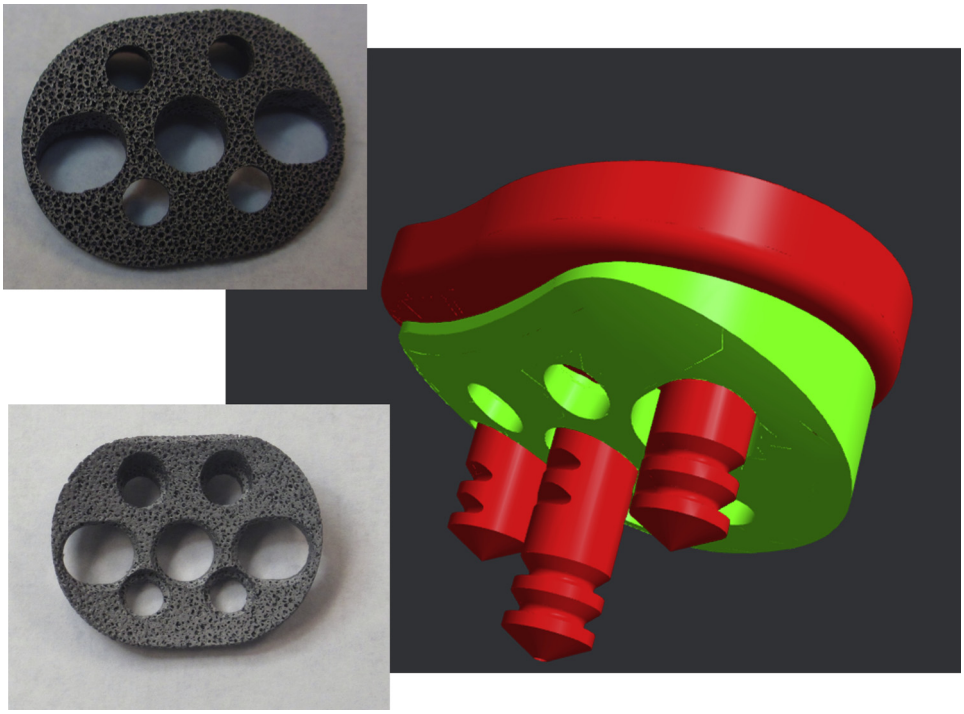

Figure 1 Porous metal glenoid augment. Glenoid component is in red and the augment in green. Note that the augment is slightly truncated on the anterior edge to allow contact of the glenoid component with the native glenoid. Reproduced with permission, Sandow and Schutz.[29]

Preoperative Procedure Simulation]; True Life Anatomy, Adelaide, Australia), 3D templating was performed to identify the optimal augment and alignment (Fig. 2). The 3D templating analysis often indicated a particular angled augment that was different from that suggested on the basis of the plain radiographs or 2D CT slice data. Further details of the technique are contained in the Supplementary Material.

Glenoid alignment was assessed using a 3D adaptation of the Friedman line.[11] In cases in which the medial scapula was not evident on the available imaging, the vault method[30] was used to assess alignment. The intention was to correct the glenoid version to neutral, with a target range of alignment to within 10° of neutral.

Humeral head alignment with respect to the glenoid was quantified as the glenoid loading index (GLI). This score was expressed as a proportion of 1, indicating the amount of humeral head anterior or posterior to the glenoid axis (typically the Friedman line).[11] A GLI of 0.5 indicated that the humeral was in line with the glenoid axis, one less than 0.5 indicated anterior translation, and one greater than 0.5 indicated that the humeral head was posterior to the central axis of the glenoid center line.

Surgical technique

Inclusion criteria, outcomes analysis, and the surgical technique for performing the anatomic total shoulder arthroplasty were consistent with the previous report.[29] No patient-specific implants, navigation, or guides were used. The intraoperative glenoid angle was assessed using a reusable angled guide referencing the anterior scapular neck (Fig. 3 and Supplementary Material). Any departure from typical glenoid shape or occurrence of large osteophytes was identified on preoperative 3D templating and taken into account.

Postoperative radiologic analysis

Satisfactory axillary views were routinely obtained, occasionally using fluoroscopy, and allowed for adequate postoperative glenoid alignment analysis in most situations. As some longer term–followed patients were unable to attend the primary treatment facility, the quality of their imaging was less reliable. Analysis of alignment was therefore performed on the best available imaging, which was not necessarily the most recent study. As a result of the excessive artifact created by the tantalum and titanium alloy, postoperative CT scanning was performed infrequently and only where adequate interpretation of the axillary plain images was not possible.

Although the target alignment was less than 10° off neutral, based on Ho and colleagues' work[16] regarding the occurrence of lucent lines with increased retroversion, 15° or less off neutral was regarded as satisfactory.

Although lucent lines around the glenoid component pegs is regarded as a marker for failure,[2] because of the intervening augment, only a portion of the actual glenoid pegs were in the native glenoid. In addition, although securing the pegs into native glenoid was deemed as an important contributor to component positioning and initial stabilization, the main function of the cement was to secure the glenoid component to the augment. To avoid cement incursion between the augment and the native glenoid, minimal cement was used in the peg holes, and

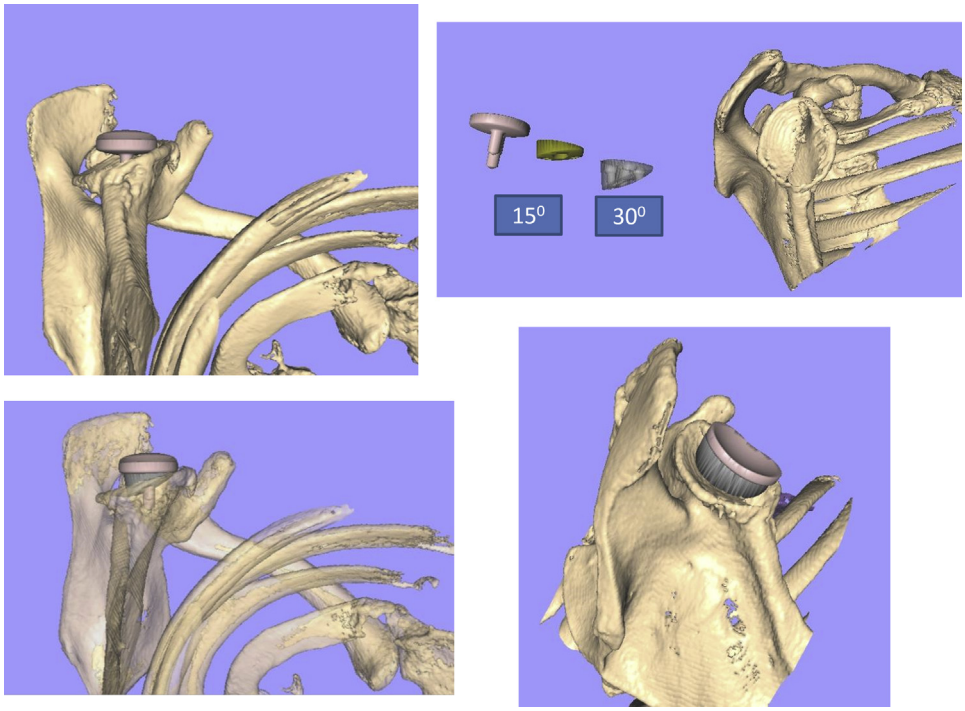

Figure 2 Preoperative 3D templating (VPOPS [Virtual Pre-Operative Planning Software]; True Life Anatomy). Wedges of 15° and 30° are trialed. (Reprinted with permission, Sandow and Schutz).[29]

pressurization was not performed. This may have created a suboptimal cementation technique in some patients.

As only a portion of the glenoid component pegs were actually in the native glenoid, lucency around the cemented pegs (if it occurred) would only be evident at the peg tips. Although lucency around the visible portion of the pegs was reviewed and reported as absent, minimal (partial and less than 2 mm), or significant (complete and greater than 2 mm), it was not deemed as a sensitive indicator for impending component failure. More importance was placed on augment displacement and re–posterior subluxation of the humeral head.

Statistical presentation

Pre- and postoperative outcomes were assessed using categorical variables described with percentages and continuous variables described with median and range. Statistical analysis was performed with GraphPad Prism 7.05 (GraphPad Software, LLC, San Diego, CA, USA), and the Mann-Whitney *U* test was used for both continuous and categorical variables. $P < .05$ was considered statistically significant.

Because of the ceiling and floor effects,[34] many patients were expected to cluster around the maximum or minimum values of the patient-reported outcome measures' ordinal scoring instruments, thereby creating a skewed data distribution. In this circumstance of non–normally distributed data, parametric descriptors were not used because this would provide an inappropriate indication of data centrality.[34] Data were therefore expressed preferentially as median and range.

To illustrate the features of various statistical presentations that may present an inaccurate impression of outcomes by obscuring outliers, the OSSs were presented as both parametric (mean and standard deviation) and nonparametric (median and range) descriptive forms. The sole purpose of descriptive statistics is to most accurately and efficiently convey the study data. To provide a more accurate graphical distribution of the data, selected scores were also presented as violin plots.

Results

Sixty-six patients (75 shoulders) underwent shoulder replacement using a porous metal wedge during January 2012 to December 2019. The study cohort were those 49 shoulders who were operated on before January 2017 and thus had a minimum of 2 years' follow-up. The median follow-up in those patients who were followed for more than 2 years was 48 months, with a range of 2-7 years. No patients were lost to follow-up, and the 4 deceased patients were scored as at their last review.

Median outcome scores demonstrate an improvement from preoperative to most recent postoperative assessment for OSS (21 to 44), ASES score (24 to 92), visual analog scale pain score (7 to 0), and forward elevation (90° to 140°), respectively (Figs. 4 and 5). These outcomes tended to reach a maximum outcome at 2 years and thereafter remained relatively constant. All pre- to postoperative

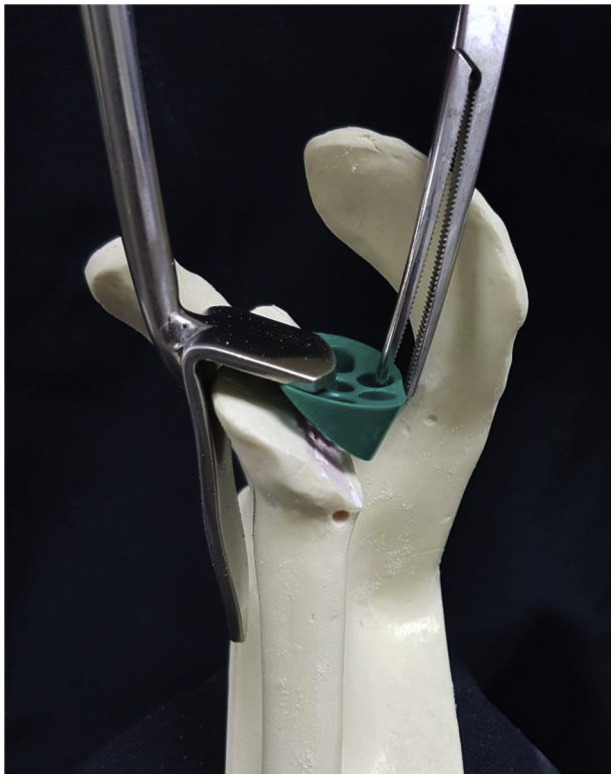

Figure 3 Model of retroverted glenoid showing alignment guide as used to assess intraoperative glenoid alignment, with 30° trial augment.

assessments were statistically significantly improved, with *P* values of less than .01.

The patient outcome scores were recorded for each patient at each follow-up point in time. This meant that a patient with a 6-year follow-up had his or her scores depicted at 2, 4, and 6 years, whereas a patient with a 2-year follow-up will only have his or her 2-year scores presented. At the most recent review, 1 patient had a pain score greater than 5, 1 patient had an OSS of less than 24, 3 patients had ASES scores of less than 50, and only 1 patient failed to achieve 90° or more forward elevation.

Of those patients who scored poorly, only 1 patient did so in each outcome instrument, and at 4 years postoperatively is regarded as a clinical failure. Her GLI was 50 and her postoperative glenoid alignment was 3° of retroversion. The cause of her poor outcome is unclear, but a failure of the subscapularis muscle attachment is suspected. All her scores are either the same or better than preoperatively, and she does not feel she is sufficiently symptomatic to warrant further surgery.

To illustrate the potential imprecision that can occur with descriptive statistics, OSS outcomes are displayed as mean and standard deviation, median and range, and as a violin (scatter) plot with median (Figures. 4). The data are clearly skewed, and the use of the parametric description creating a standard deviation that exceeds the score range is problematic.

In 28 patients, a 15° wedge was used, and in the other 21 patients, a 30° PMGA was used. Glenoid retroversion improved from median 22° retroversion (range 15°-45°) to 4° (range 17° to anteversion 15°) (Table I). As expected, the degree of correction was greatest with the larger wedge, but the larger wedges also achieved the best final alignment. Only 4 patients were outside the target range (less than 10° off neutral) and, of those, 2 failed to achieve a satisfactory correction of under 15° off neutral. The preoperative and most recent postoperative axillary views of all patients with more than a 2-year follow-up are available in the Supplementary Material.

GLI was corrected from a preoperative median of 0.81 (range 0.64-0.96) to a postoperative median of 0.52 (range 0.25-0.68), with all but 1 patient under 0.65. Two cases demonstrated a degree of overcorrection with a GLI of below 0.40. One of these patients had a pain score of 5, but forward elevation of 140°, and OSS of 42, and the other had a pain score of zero, flexion to 90°, and an OSS of 37.

No cases of augment or glenoid component displacement was observed, but there was 1 minor peg perforation and 3 screw breakages. Four cases demonstrated some minor lucency around the central peg.

In several cases, one or both of the anterior screws appeared to have broken through the anterior screw holes of the augment and were positioned in the glenoid vault deeper than intended, but this appeared to have had no effect on the position or apparent incorporation of the PMGA implant.

Complications

One patient has undergone revision to a reverse shoulder replacement for infection with *Cutibacterium* (formerly *Propionibacterium*) *acnes* at 18 months postoperatively. This was a patient with longstanding traumatic incomplete quadriplegia and who was partially wheel chair dependent. To correct his underlying glenoid retroversion and early osteoarthritis changes, he initially underwent a posterior glenoid opening osteotomy; however, this failed to address his posterior shoulder subluxation and was associated with an acceleration of his arthritic changes.

Because of his severe pain, age of 40 years, and compromised deltoid power, a reverse shoulder replacement was deemed undesirable, and so the anatomic replacement with version correction was performed. Although he achieved almost perfect realignment, he had persistent low-grade pain and discomfort with progressive glenoid and augment loosening that required a single-stage revision to a custom reverse replacement (Zimmer-Biomet). He was not formally followed up after the revision, but his eventual outcome was only fair.

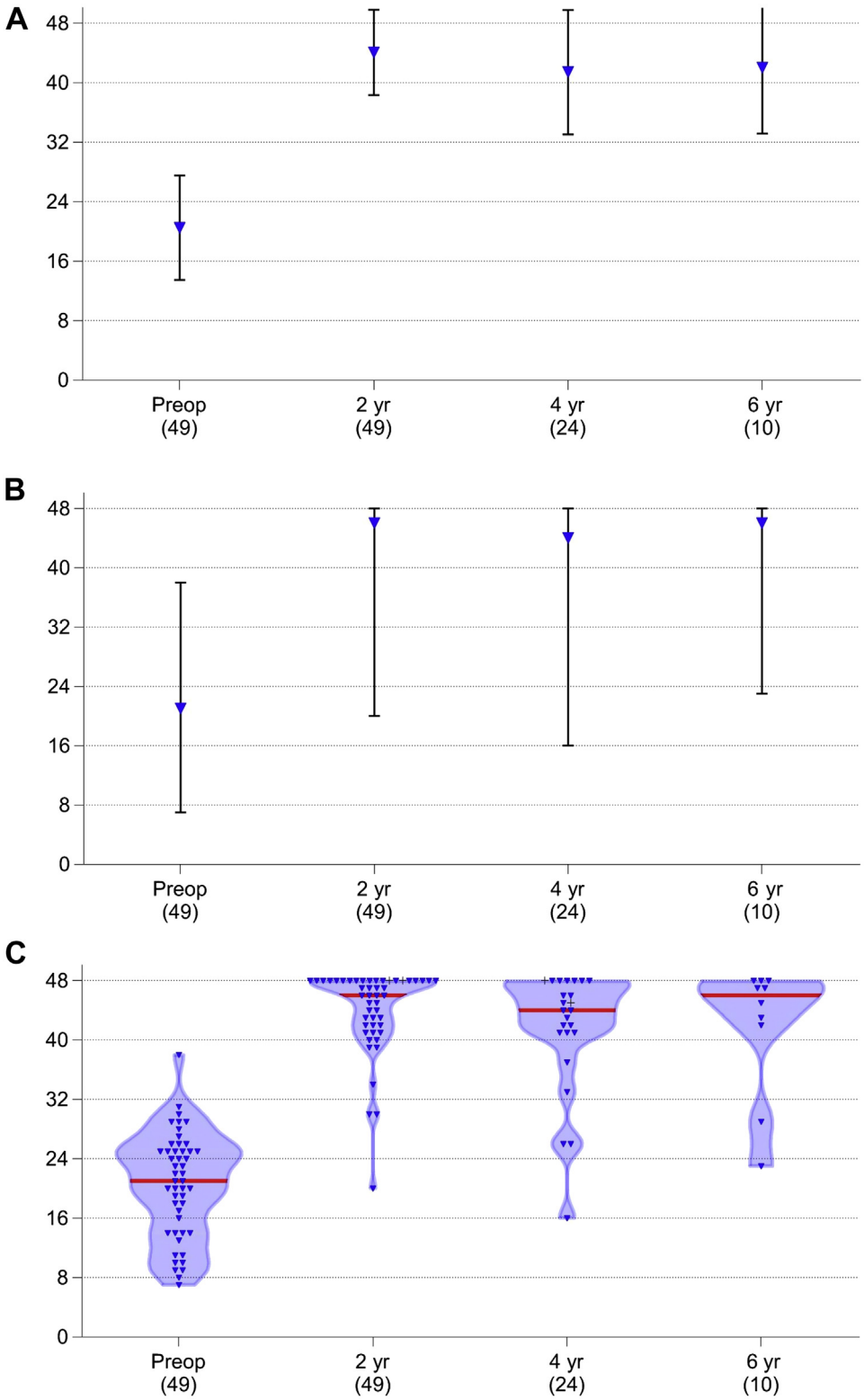

Figure 4 Oxford Shoulder Score (maximum score 48) at preoperation and at 2, 4, and 6 years postoperatively, presented as (A) mean and standard deviation, (B) median and range, and as (C) violin scatter plot with the median in red. Crosses indicate the final scores for patients who have died. Numbers of patients at each period shown in brackets.

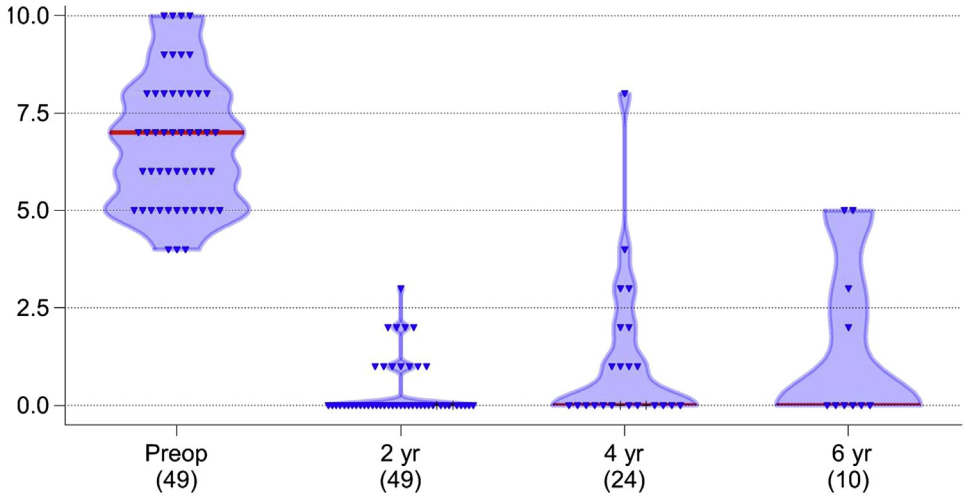

Figure 5 VAS pain scores (10 = severe pain, 0 = no pain). Violin plot of preoperative scores and those at 2, 4, and 6 years postoperatively; the median is marked in red. Crosses indicate the final scores for patients who have died. Numbers of patients at each period are shown in brackets.

Table I Glenoid version correction showing pre- and postoperative glenoid alignment.

	Retroversion from neutral (preoperative to latest review)		
	Preoperation	Postoperation	Correction
All	−22.05° (−46.15° to −12.95°)	−3.75° (−16.95° to +15.95°)	−15.95° (−34.65° to −2.25°)
15° wedge	−19.00° (−24.10° to −12.95°)	−6.10° (−16.95° to +15.95°)	−13.45° (−33.95° to −2.25°)
30° wedge	−26.05° (−46.15° to −22.00°)	−1.90° (−11.70° to +3.70°)	−25.30° (−34.65° to −13.45°)

Values are median (range). Alignment is based on the latest suitable imaging using 2D or 3D computed tomographic imaging preoperatively and plain radiograph axillary view postoperatively. Because of preoperative shoulder stiffness, well aligned axillary view was often not possible. Retroversion denoted with minus sign.

This patient and the patient with poor clinical scores were regarded as the only failures in the series. Apart from the single case of infection, there have been no revisions, and no episodes of dislocation, nerve palsy, or definite subscapularis muscle failure.

Discussion

Anatomic shoulder arthroplasty has been reported to have clinical outcomes superior to reverse shoulder replacement [10,23,32]; however, without well-conducted comparative studies, the relative advantages of the various options for addressing arthritic shoulders with retroverted glenoids remain conjectural. Alentorn-Geli et al[2] published one of the few such studies regarding alternatives for addressing the arthritic biconcave glenoid. At a minimum of 2 years' follow-up, both anatomic replacement (with modest version correction plus posterior capsular plication) and reverse shoulder arthroplasty achieved satisfactory results with no revisions in either cohort. The reverse arthroplasty patients demonstrated no adverse radiologic parameters; however, 26% of the anatomic replacements were classified as radiographic failures, with variable degrees of posterior subluxation, peg lucency, peg perforation, and component loosening. Despite the poor radiographic appearance, the functional outcome in the anatomic replacement cohort was superior to that of the reverse replacements.

For the current study, and consistent with the findings of Alentorn-Geli et al,[2] the premise was that performing an anatomic total shoulder replacement with an intact rotator cuff but retroverted arthritic glenoid was to be preferred over a reverse arthroplasty if posterior glenoid deficiency could be satisfactorily addressed. Implanting the glenoid in retroversion has been associated with a high failure rate.[21]

Although eccentric reaming can correct glenoid version,[35] the extent of correction,[1,19,22] risk of perforation,[1,19,33] and compromise of the subchondral bone[6,33] render this option only suitable for minor retroversion deformity (less than 15°).[6] As such, for an anatomic shoulder arthroplasty in a more severely retroverted arthritic glenoid, building up the posterior glenoid is the preferred solution.

The materials available to correct the deficiency include autologous or allograft bone, polyethylene, or

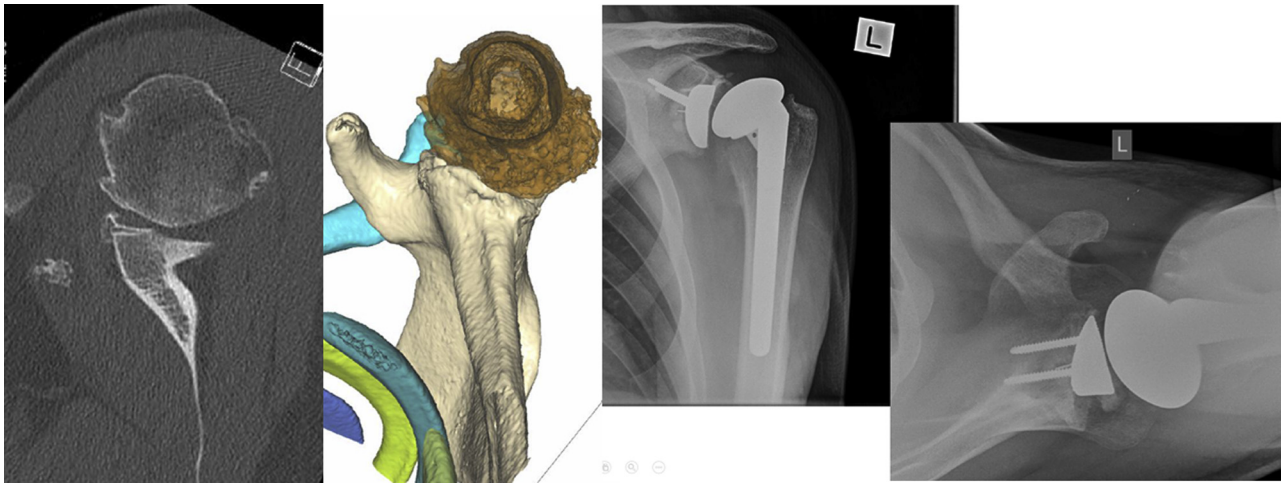

Figure 6 Clinical case example correction. A 46-year-old male with 3 years of severe pain and loss of motion. Preoperative 2D computed tomography (CT) scan and 3D modeling (VPOPS; True Life Anatomy) identified that a 30° PMGA augment would best correct retroversion, and this was confirmed on postoperative plain axillary radiograph. Patient required bilateral anatomic total shoulder arthroplasty.

some form of metallic device. Autologous humeral head bone graft has been demonstrated to effectively correct the bone deficiency [24] but has a high failure rate and is technically challenging.[12,22] This makes some form of augmented glenoid component a suitable choice; however, to date, there is no clear advantage of one design over another, and there is a lack of understanding of longer-term outcomes.[14]

In considering the augmented glenoid options to address the glenoid deficiency, it was evident that a wedge shape had better capacity for version correction,[15] loading characteristics,[3] and less bone removal[3,18] than various alternatives.

Wedge-shaped polyethylene can achieve satisfactory loading and version correction, but it has been shown to have poor mechanical stability when compared to a stepped device[16] or asymmetric reaming,[35] though these findings contrast with more recent work by Sabesan et al.[28] However, wedged plastic components of greater than 16° have been demonstrated to have a high loosening and component fracture rate, and Priddy et al[26] recommend not using such devices because of their unacceptable failure rate. Placing polyethylene components with a bone interface at an angle to the primary load appears to create an unacceptable level of shear force.[35]

Porous bone ingrowth metal has been successfully used in hip and knee arthroplasty, even if implanted in shear.[8] Primary fixation, generally with either screws or pegs, appears to adequately stabilize the device to allow device incorporation by progressive bone ingrowth.[7] On the basis of extensive and positive long-term lower limb experience with a range of generically shaped porous metal augments to address the bone deficiency, it was felt that a hybrid solution of a cemented HDPE standard glenoid component and a porous metal augment may provide a hitherto untested solution for the shoulder (Fig. 6). The PMGA replicated the capabilities of a wedge-shaped autologous bone graft, but without the technical difficulties of bone preparation and fixation, or the propensity for graft collapse in the medium to longer term. Preliminary outcomes have already been reported.[29]

Notably, such a device acts more like a bone graft than a metal-backed glenoid component. Unlike truly metal-backed glenoid components, the PMGA wedges used in this study largely retained subchondral bone plate and did not excessively lateralize the joint line. They simply acted to create an optimal axial, sagittal, and coronal glenoid surface onto which a standard glenoid component was implanted.[29]

Limitations

The limitations and concerns regarding this review include the issues raised if revision of the augment is required. However, the uniplanar bone-device interface of the PMGA should be easily addressed with a suitable curved and thin osteotome, compared with the existing porous metal devices such as the monobloc (Zimmer TM, Warsaw, IN, USA) or modular bone ingrowth metal-backed glenoid components (Lima, Udine, Italy), in which the porous metal is inserted into the glenoid vault. This is only a theoretical consideration, as revision of an ingrown porous wedge has not been required. In the case of the infected patient, the PMGA was quite loose; however, the glenoid component was strongly bonded to the PMGA by the polymethyl methacrylate cement, providing some validation that such hybrid fixation is effective. However, should the HDPE fail as a result of wear, the augment could be left

in place, the plastic and cement removed, and a new glenoid implant inserted into the incorporated porous metal device.

Conclusion

The theoretically attractive solution of a porous metal wedge for the retroverted glenoid has been used in a prospective series of 66 patients and has achieved satisfactory clinical and radiologic outcomes with a follow-up of up to 7 years. No patients have undergone revision for aseptic loosening, all but 2 patients have had their glenoids corrected to within 15° of neutral, and there have been no longer-term subluxations, joint loosening, dislocations, or other complications documented. There was a single occurrence of a peg perforation and several screw breakages, but no indication of progressive or impending failure, such as implant displacement, significant lucency, or posterior subluxation.[31]

Although there remain multiple options for addressing glenoid retroversion, a recent comparative cohort study[2] revealed that although reverse shoulder replacements were radiologically superior, and anatomic replacement had a 30% incidence of resubluxation and 24% incidence of radiologic failure at 2 years, the patient outcome scores were better for the anatomic device. This suggests that the anatomic replacement may have an advantage over reverse shoulder replacement in terms of function if the bone deformity can be addressed.

Porous metal augments are a durable solution for bone defects in lower limb arthroplasty; this would appear to be reflected in this upper limb series. Although this series could only address follow-ups of up to a median of 47 months, the absence of any signs of impending failure may suggest that this result will be sustained. Based on these results, the PMGA appears to be a viable and attractive option for addressing glenoid retroversion in arthritic shoulders with the cuff intact.

Disclaimer

Michael Sandow has been involved in and has a commercial interest in the development of the 3D planning software discussed in this article (True Life Anatomy, Adelaide, Australia), and may receive something of value from a commercial party associated with the subject of this study. Neither author has received any benefit or payment, direct or otherwise, from the prosthesis manufacturer. Chen Tu, his immediate family, and any research foundations with which he is affiliated have not received any financial payments or other benefits from any commercial entity related to the subject of this article.

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Supplementary Data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jse.2020.01.101.

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