Custom Reverse Shoulder Arthroplasty for Severe Postoperative Glenoid Bone Defects: A Retrospective Case Series

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ABSTRACT

Introduction: Glenoid bone loss complicates revision reverse shoulder arthroplasty. Patient-specific 3D-printed glenoid implants allow accurate reconstruction of severe defects. **Objective:** To evaluate the clinical and radiographic outcomes of customized glenoid baseplates in revision reverse shoulder arthroplasty with severe glenoid defects, and to record intraoperative and postoperative complications. **Materials and Methods:** A retrospective series of eight consecutive patients (June 2022–May 2023) with Gohlke type ≥3 defects who underwent revision reverse shoulder arthroplasty with 3D-planned titanium glenoid baseplates based on computed tomography. Range of motion, function, pain, surgical time, and radiographic integration were analyzed, with a 12-month follow-up. **Results:** Range of motion improved significantly: forward elevation increased by 78.8° ($p < 0.001$), external rotation by 7.5° ($p = 0.019$), and internal rotation improved from the gluteal level (trochanter–L5) to a mean of T12 (range: T7–gluteal level). Pain decreased by 6.4 points ($p < 0.001$). The Constant-Murley score increased by 48.9 points ($p < 0.001$). Complete osseointegration was observed in 7 cases; the remaining case showed radiolucent lines without loosening. No major complications were recorded. **Conclusions:** In revision reverse shoulder arthroplasty with severe glenoid bone defects, 3D-printed glenoid baseplates restore anatomy, significantly improve function, and reduce pain at one year, with a high rate of integration and low morbidity.
Keywords: Reverse shoulder arthroplasty; glenoid bone defects; patient-specific implants; 3D printing; revision surgery.
Level of Evidence: IV

Artroplastia inversa de hombro personalizada para defectos óseos glenoideos severos posoperatorios. Estudio retrospectivo de casos clínicos

RESUMEN

Introducción: La pérdida ósea glenoidea complica las revisiones de una artroplastia inversa de hombro. Los implantes glenoideos personalizados impresos en 3D permiten reconstruir, con precisión, defectos severos. **Objetivos:** Evaluar los resultados clínicos y radiográficos de las metaglenas personalizadas en revisiones de artroplastias inversas de hombro con defectos glenoideos severos, así como registrar las complicaciones intra y posoperatorias. **Materiales y Métodos:** Serie retrospectiva de 8 pacientes consecutivos (junio 2022-mayo 2023) con defectos tipo Gohlke ≥3 sometidos a una artroplastia inversa de hombro de revisión con metaglenas de titanio planificadas en 3D sobre una tomografía. Se analizaron la movilidad y la función, el dolor, el tiempo quirúrgico y la integración radiográfica; seguimiento de 12 meses. **Resultados:** Los rangos de movilidad se incrementaron: la elevación anterior aumentó 78,8° ($p < 0,001$); la rotación externa, 7,5° ($p = 0,019$); la rotación interna, desde el nivel glúteo (trocánter-L5) a un promedio de T12 (rango T7-nivel glúteo). El dolor disminuyó 6,4 puntos ($p < 0,001$). La escala de Constant-Murley aumentó 48,9 puntos ($p < 0,001$). Se constató la integración ósea completa en 7 casos; el restante tenía líneas radiolúcidas sin aflojamiento. No se registraron complicaciones mayores. **Conclusiones:** En las revisiones de artroplastias inversas de hombro con defectos glenoideos severos, las metaglenas impresas en 3D restauran la anatomía, mejoran significativamente la función y reducen el dolor al primer año, con una alta tasa de integración y baja morbilidad.
Palabras clave: Artroplastia inversa de hombro; defectos óseos glenoideos; implantes personalizados; impresión 3D; revisión quirúrgica.
Nivel de Evidencia: IV

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INTRODUCTION

In recent decades, reverse shoulder arthroplasty has emerged as an effective treatment option for rotator cuff tear arthropathy. Due to its favorable outcomes, its indications have expanded to include four-part proximal humeral fractures in elderly patients, massive irreparable rotator cuff tears without arthropathy, and revision of failed osteosynthesis and hemiarthroplasties.[1-3]

Loss of glenoid bone stock is a common and challenging problem when performing reverse shoulder arthroplasty.[4,5] Glenoid bone defects are more frequently found in revision procedures, due to prosthetic loosening (septic or aseptic), periprosthetic glenoid fractures, and traumatic defects secondary to migration or protrusion of implants used for proximal humeral fractures.[6-8]

Various complex techniques have been described to address glenoid bone loss, including one- or two-stage revision procedures using iliac crest or humeral head bone grafts, the use of metal-augmented baseplates, Mark Frankle's alternative centerline technique, and even salvage hemiarthroplasty.[4,5] More recently, patient-specific implants manufactured using 3D printing based on precise preoperative digital planning have been introduced, which adapt to each patient's specific anatomical defects. This technology provides a better management of complex glenoid bone defects by optimizing surgical accuracy and primary implant stability.[5–11]

Given the novelty of this technology and the limited available evidence, we have not yet determined which technique provides the best outcomes.

The aim of this study was to evaluate the clinical and radiological outcomes at one year of follow-up in patients undergoing revision reverse shoulder arthroplasty for severe postoperative glenoid bone defects using patient-specific glenoid components, as well as to record intraoperative and postoperative complications.

MATERIALS AND METHODS

A retrospective analysis was conducted of a consecutive series of patients with severe glenoid bone defects associated with prior surgery, treated with reverse shoulder arthroplasty using patient-specific glenoid implants, between June 2022 and May 2023. Adults with severe postoperative glenoid bone defects (≥3 according to the Gohlke classification) and a minimum clinical and radiographic follow-up of one year were included. Patients undergoing primary arthroplasty, those with a history of shoulder infection, and those with neurological deficits in the affected limb were excluded.

Glenoid defects were classified according to the Gohlke classification.[12]

- Type 1: mild bone loss, central or eccentric, with retroversion <15°.
- Type 2: moderate contained bone loss, with an intact glenoid vault.
- Type 3: severe eccentric defect with retroversion >20° or significant loss of glenoid width.
- Type 4: moderate medialization of the glenoid surface.
- Type 5: defect with residual depth <10 mm for implant fixation.

All patients underwent a preoperative protocol that included true anteroposterior and axial radiographs of the affected shoulder, thin-slice computed tomography (CT) with 3D reconstruction, and laboratory tests including erythrocyte sedimentation rate and C-reactive protein.

In the postoperative period, clinical and radiographic evaluations were performed immediately after surgery, at 1 month, 6 months, 1 year, and at the final follow-up. Operative time (in minutes) was recorded based on surgical reports, and intraoperative and postoperative complications were documented during scheduled follow-up visits.

The treating surgeon assessed shoulder range of motion preoperatively and at follow-up visits. Evaluation parameters included active motion, measured as forward elevation in the scapular plane, external rotation with the elbow at the side, and internal rotation estimated according to the highest vertebral level reached by the thumb. In addition, pain was assessed using the visual analog scale, and function was evaluated using the Constant–Murley score.

Statistical Analysis

Categorical variables are expressed as frequencies and percentages, and continuous variables as mean and standard deviation or median and interquartile range, depending on their distribution. Normality of differences between pre- and postoperative values was assessed using the Shapiro–Wilk test. When normality was confirmed, the paired Student's t-test was used; otherwise, the nonparametric Wilcoxon signed-rank test was applied. A p value <0.05 was considered statistically significant. All analyses were performed using GraphPad Prism 9.0 (La Jolla, CA, USA).

Custom Implant Design

Preoperative computed tomography (CT) scans were used for implant design and manufacturing. Preoperative planning was performed using 3D Slicer (version 5.6.2) and Meshmixer (version 3.5.474, Autodesk Inc., San Rafael, CA, USA). This allowed detailed evaluation of the bone defect and creation of a 3D biomodel of the patient's scapula (Figure 1).

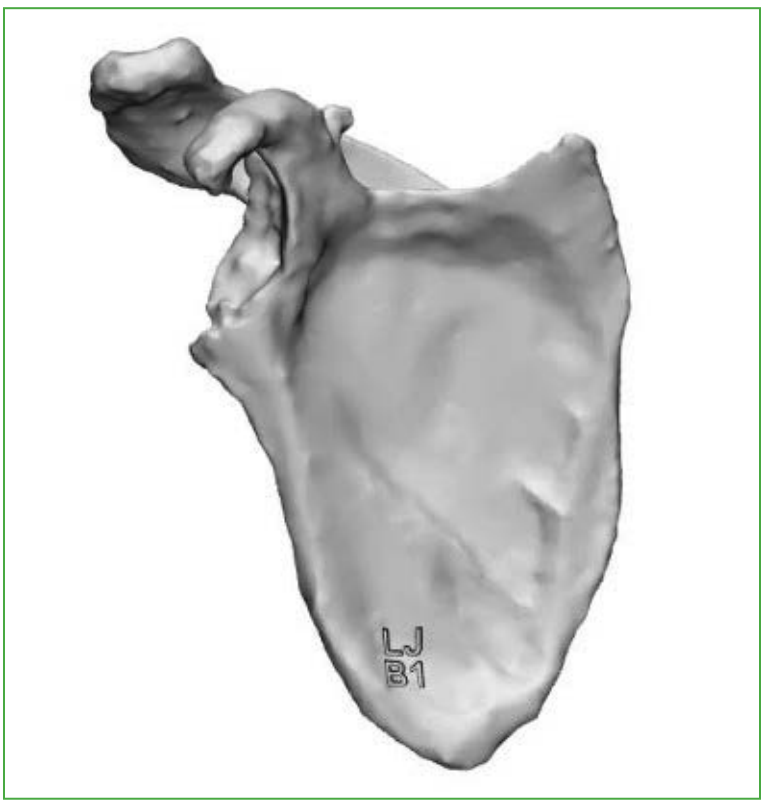

Figure 1. Use of 3D computed tomography for preoperative planning.

The patient-specific glenoid baseplate was designed in collaboration with a biomedical engineer, developing a component precisely adapted to the patient's bone defect, with the aim of reproducing the glenoid lateralization, inclination, and version specified by the surgeon (Figure 2).

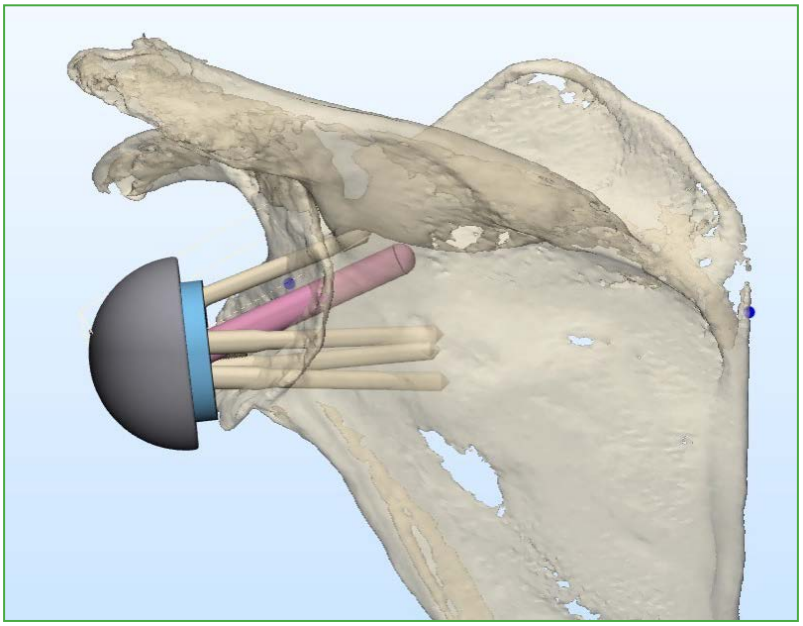

Figure 2. Design of the glenoid baseplate adapted to the patient's bone defect.

When the bone defect was so severe that premorbid lateralization could not be reliably estimated, superimposition was performed using a CT scan obtained prior to the initial surgery (if available) or, alternatively, from the contralateral shoulder (Figure 3).

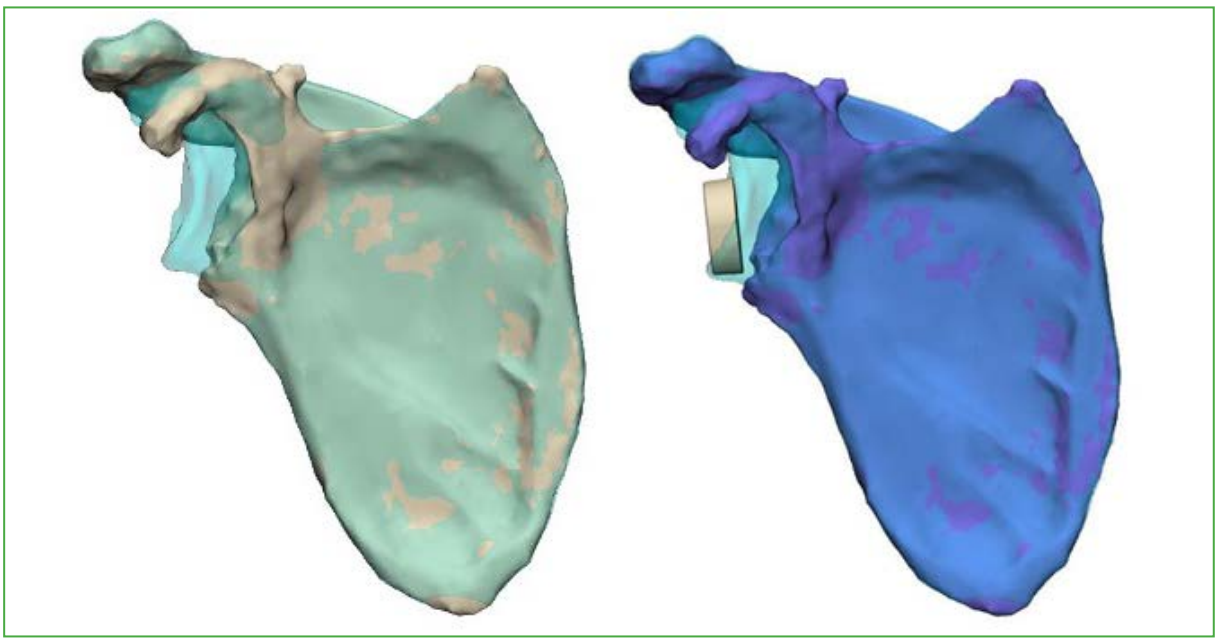

Figure 3. Use of preoperative CT scans and superimposition to calculate lateralization values.

The direction and length of the screws were subsequently planned according to each patient's bone quality and bone stock. The goal, whenever possible, was to achieve at least 1 cm of contact between the central peg and native bone, along with the placement of at least two screws measuring 4.5 mm in diameter and 30 mm in length (Figure 4).

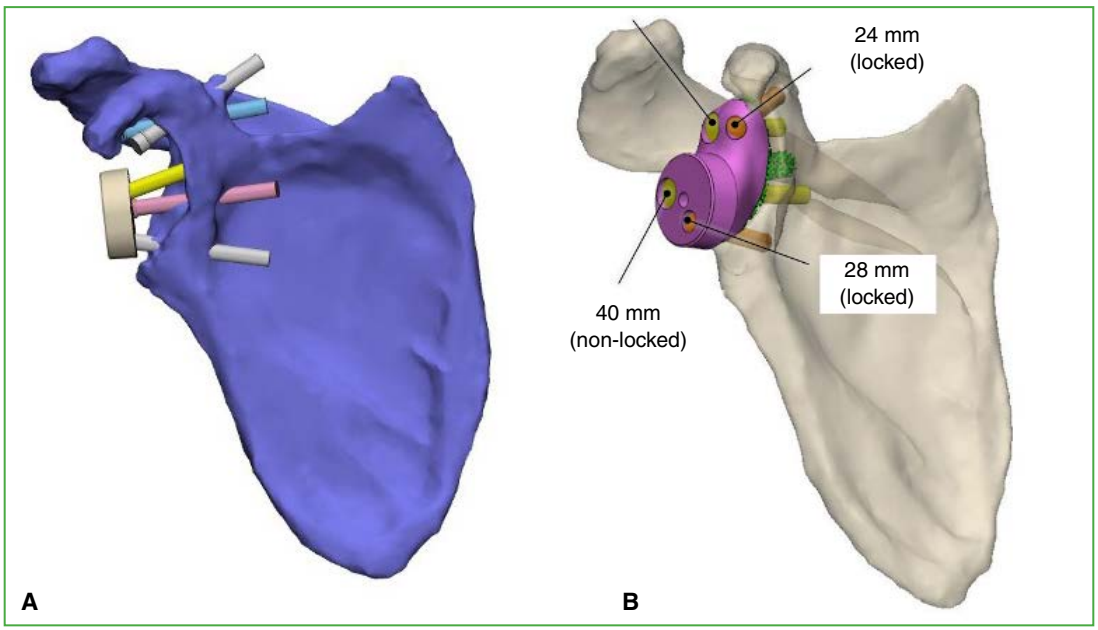

Figure 4. Planning of screw orientation (A) and measurement (B) for the glenoid baseplate.

The custom baseplate was designed to be Morse taper-compatible with a 36-mm Unique® glenosphere (Bioprotece, Villa Ballester, Buenos Aires, Argentina).

Once the implant was designed, patient-specific surgical guides were developed, and the implant was manufactured using 3D printing in titanium (Figures 5 and 6).

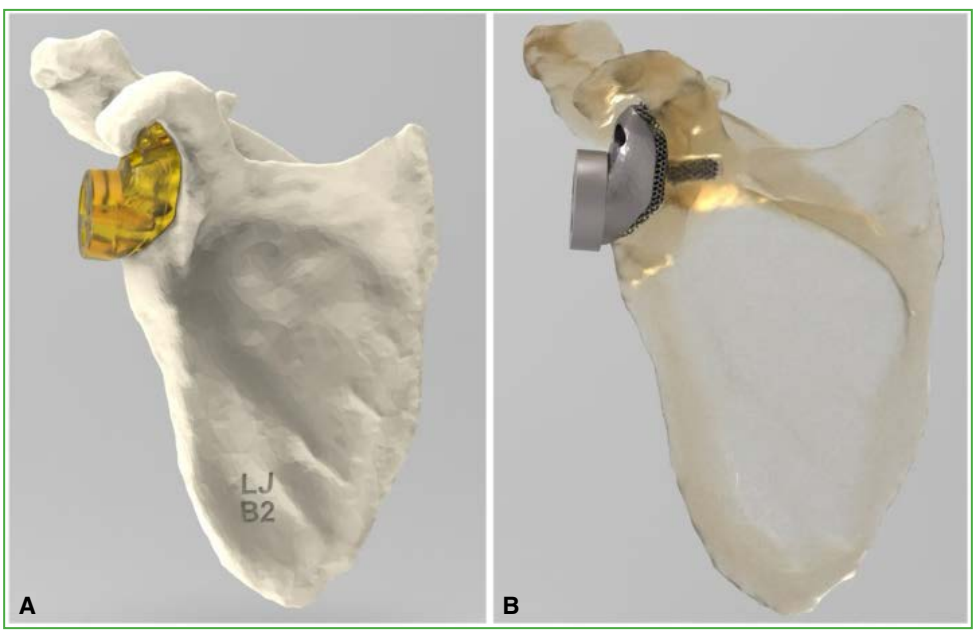

Figure 5. A. Patient-specific glenoid baseplate model in plastic. **B**. Titanium glenoid baseplate model adapted to the glenoid defect.

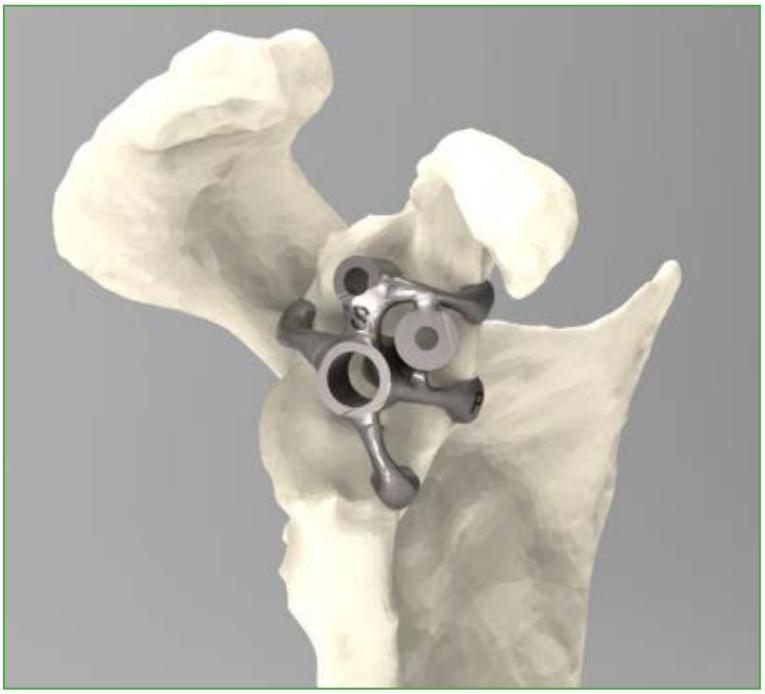

Figure 6. Patient-specific surgical guides tailored to the defect.

The guides were designed with four points of support on peripheral glenoid landmarks, considering retractor placement, to allow precise positioning of the central guide pin or drill.

Prior to final manufacturing, full scapular biomodels and full-scale plastic prototypes of the baseplates were produced (Figure 7). This enabled the surgeon to become familiar with the intraoperative scenario and, if satisfactory, approve the final design.

The definitive patient-specific baseplate was manufactured using 3D printing technology in ELI grade 5 trabecular titanium, with a trabecular metal interface of 0.4 mm thickness, 70% porosity, and an additional sandblasted surface treatment to enhance osseointegration (Figures 8 and 9).

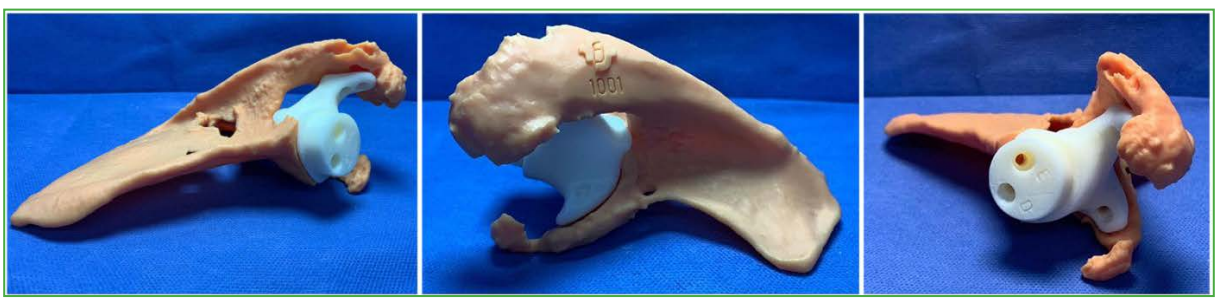

Figure 7. Biomodels of the entire scapula and full-scale plastic prototypes of the glenoid baseplates.

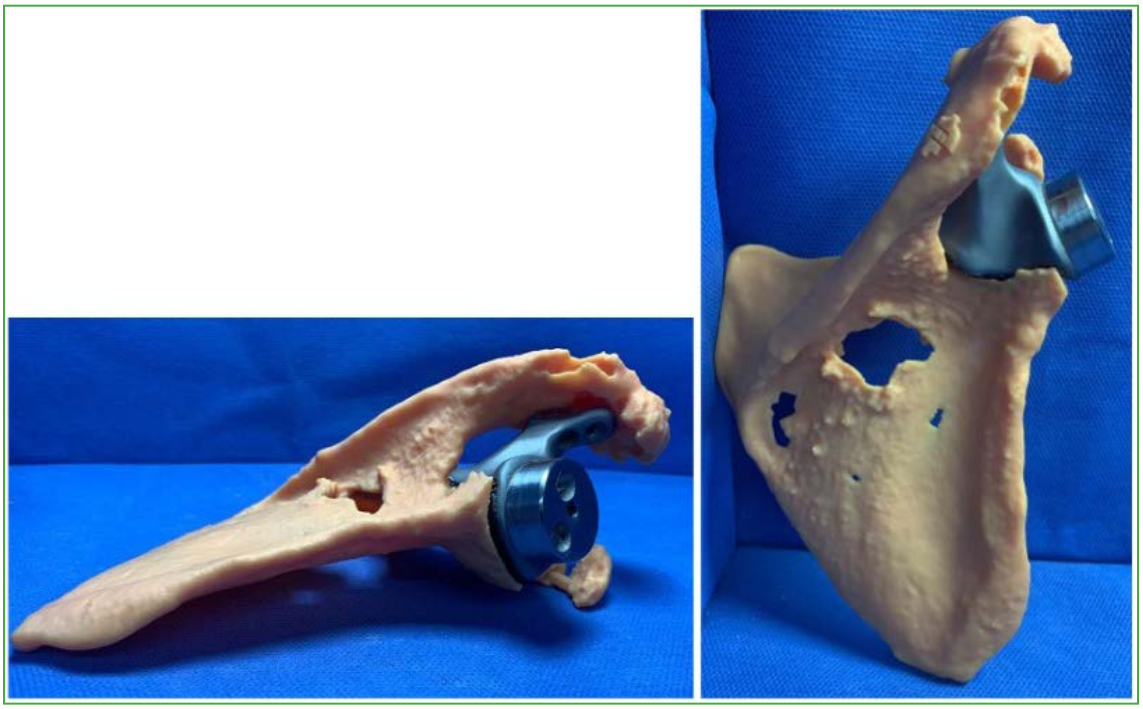

Figure 8. Patient-specific glenoid baseplate made of trabecular titanium.

Figure 9. Glenosphere coupled to the patient-specific glenoid baseplate.

Surgical Technique

Patients underwent surgery in the beach-chair position under sedation and regional anesthesia of the affected limb. A deltopectoral approach was used in all cases. After release of adhesions and resection of fibrotic tissue, osteosynthesis hardware or prosthetic components were removed as appropriate.

Following circumferential release of the glenoid, bony landmarks were identified for placement of the 3D-printed titanium guide, which was used as a template to guide drilling for the central peg (Figure 10).

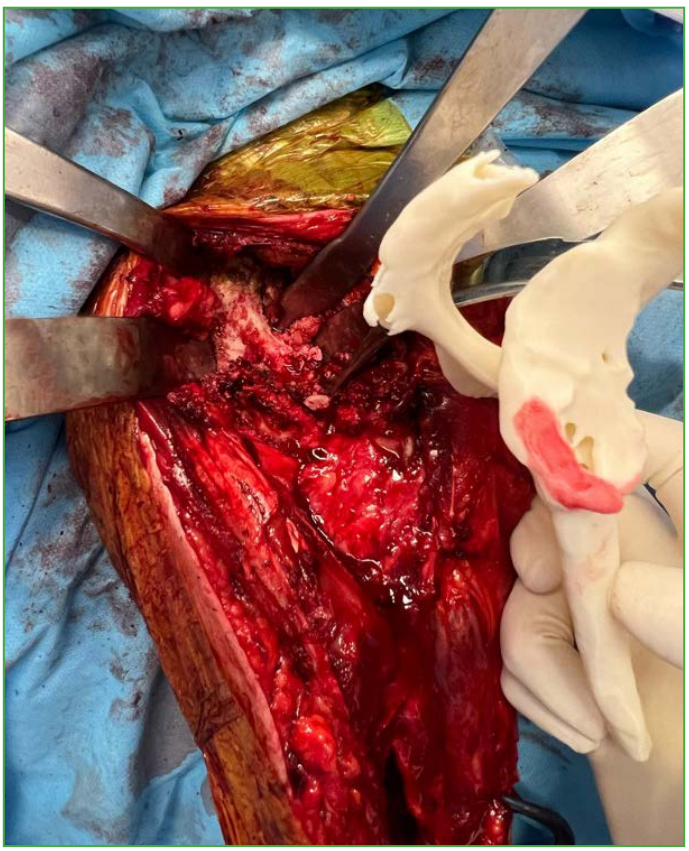

Figure 10. Glenoid defect and bony landmarks for positioning the 3D guide.

A full-scale plastic prototype of the baseplate was used to verify fit, followed by implantation of the definitive patient-specific component (Figures 11 and 12).

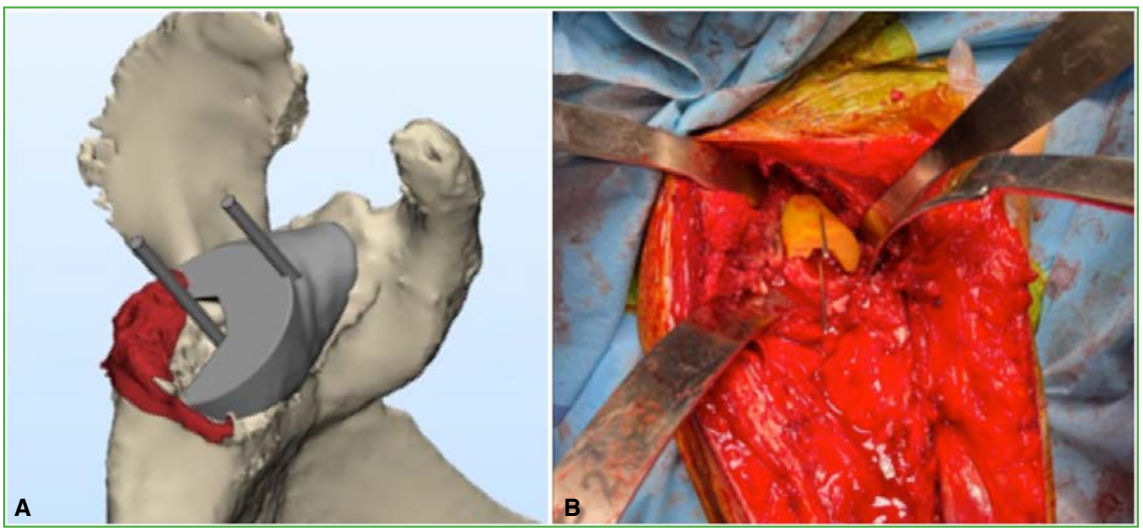

Figure 11. A. Planning of central pin placement. **B.** Placement of the central post pin and reaming stop guide using the plastic glenoid baseplate prototype.

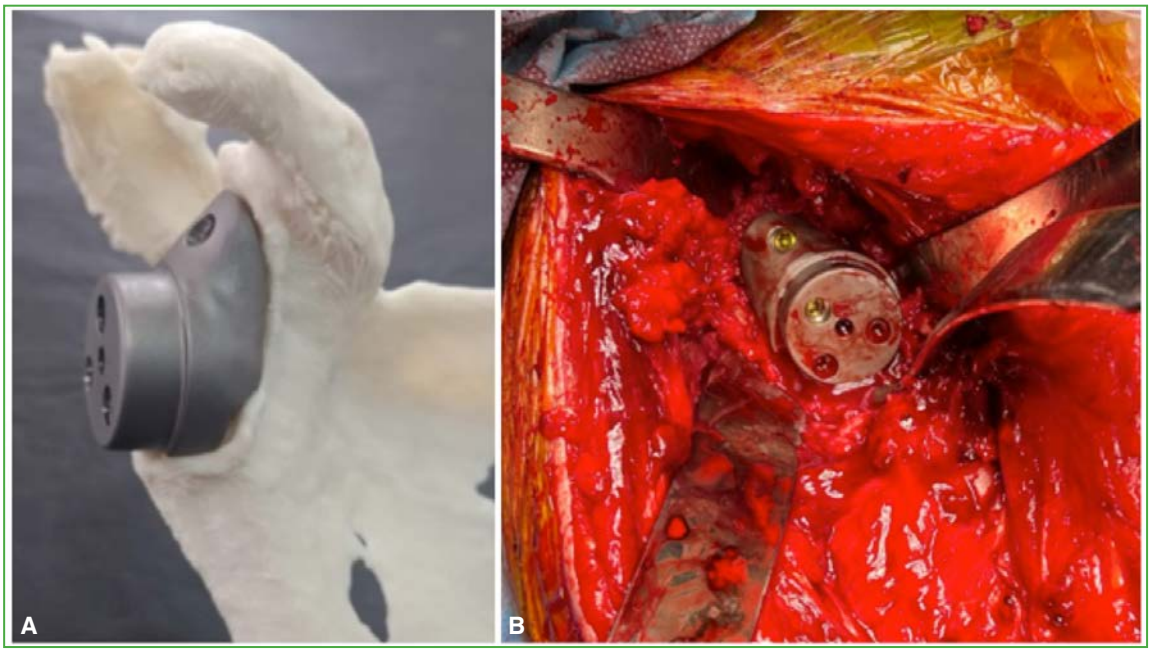

Figure 12. **A.** Final patient-specific implant in a plastic model. **B.** Final patient-specific implant in vivo.

The humeral component was addressed as required (either as a primary implantation, revision procedure, or retention of the existing implant) depending on the case.

All patients followed the same postoperative protocol: immobilization in a sling for the first 6 weeks, combined with gentle passive range-of-motion exercises. From week 6 onward, assisted active exercises were introduced to improve mobility, followed by progressive strengthening beginning at week 12. Full recovery was expected within 6 to 12 months.

RESULTS

The series comprised eight consecutive patients with a minimum follow-up of 12 months. The mean age was 67.3 years (range 38-84). Seventy-five percent were women and 25% were men. The affected shoulder was the right in six patients and the left in the remaining two (Table 1).

Table 1. Demographic data.

Variables		
Age	67.3 years (38–84 years)	
Sex	Male	Female
	6 (75%)	2 (25%)
Dominant side	Right	Left
	6 (75%)	2 (25%)

The mean operative time was 142.5 minutes (range 105-180) (Table 2).

Table 2. Operative time per patient.

Patient	Operative time (min)	Preoperative diagnosis	Number of previous surgeries	Treatment
1	145	Glenoid loosening	3	Glenoid revision
2	105	Spacer	4	Humeral + glenoid revision
3	155	Failed hemiarthroplasty	2	Humeral + glenoid revision
4	180	Failed osteosynthesis	1	Humeral + glenoid revision
5	180	Failed osteosynthesis	1	Humeral + glenoid revision
6	120	Failed hemiarthroplasty	1	Humeral + glenoid revision
7	130	Glenoid loosening	1	Glenoid revision
8	125	Failed osteosynthesis	2	Humeral + glenoid revision

The distribution of bone defects according to the Gohlke classification was as follows: type 3 (25%), type 4 (50%), and type 5 (25%).

In this series, significant improvements were observed in all analyzed variables. Forward elevation increased by a mean of 78.8° (95% confidence interval [CI] 65.0-92.5; $p < 0.001$), external rotation improved by 7.5° (95% CI 1.6-13.4; $p = 0.019$), and internal rotation improved from the gluteal level (trochanter-L5) to a mean of T12 (range T7-gluteal level). Pain, measured using the visual analog scale, decreased by 6.4 points (95% CI -7.6 to -5.2; $p < 0.001$). The Constant–Murley score increased by 48.9 points (95% CI 42.6-55.1; $p < 0.001$) (Table 3).

Table 3. Relationship between preoperative and postoperative clinical and functional parameters.

	Preoperative values (SD)	Postoperative values (SD)	p
Anterior elevation	45 ± 14.1°	123.8 ± 16.9°	<0.001
External rotation	8.8 ± 9.9°	16.2 ± 5.2°	0.019
Internal rotation	Gluteus-L5	T12 (T7-gluteus)	0.022
VAS	8.0 ± 1.3	1.6 ± 0.7	<0.001
Constant-Murley Scale	16.9 ± 4.7	65.8 ± 9.6	<0.001

VAS = visual analog scale.

Radiographic analysis showed appropriate implant integration in seven of the eight cases (Figures 13 and 14).

Figure 13. A and B. Anteroposterior and axial shoulder radiographs, one-year postoperative follow-up, showing correct implant osseointegration. **C**. Functional outcome one year after surgery.

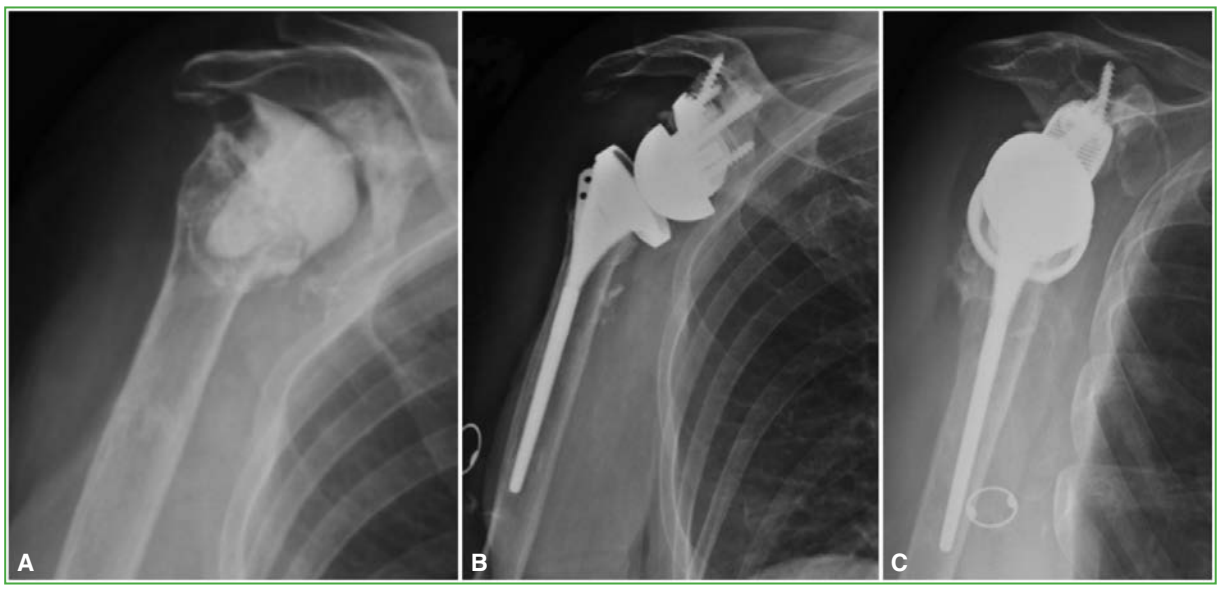

Figure 14. A. Preoperative radiograph of a patient with a severe glenoid defect. **B and C**. Anteroposterior and lateral shoulder radiographs, one-year postoperative follow-up, showing correct implant osseointegration.

In one patient with sequelae of a previously treated proximal humeral fracture with a PHILOS plate and severe glenoid erosion caused by the implant screws, loosening of the glenoid baseplate with mild migration was observed. This resulted in moderate functional limitation, although pain control remained adequate. The patient was satisfied with pain relief and declined further surgical intervention; therefore, conservative management was adopted (Figure 15).

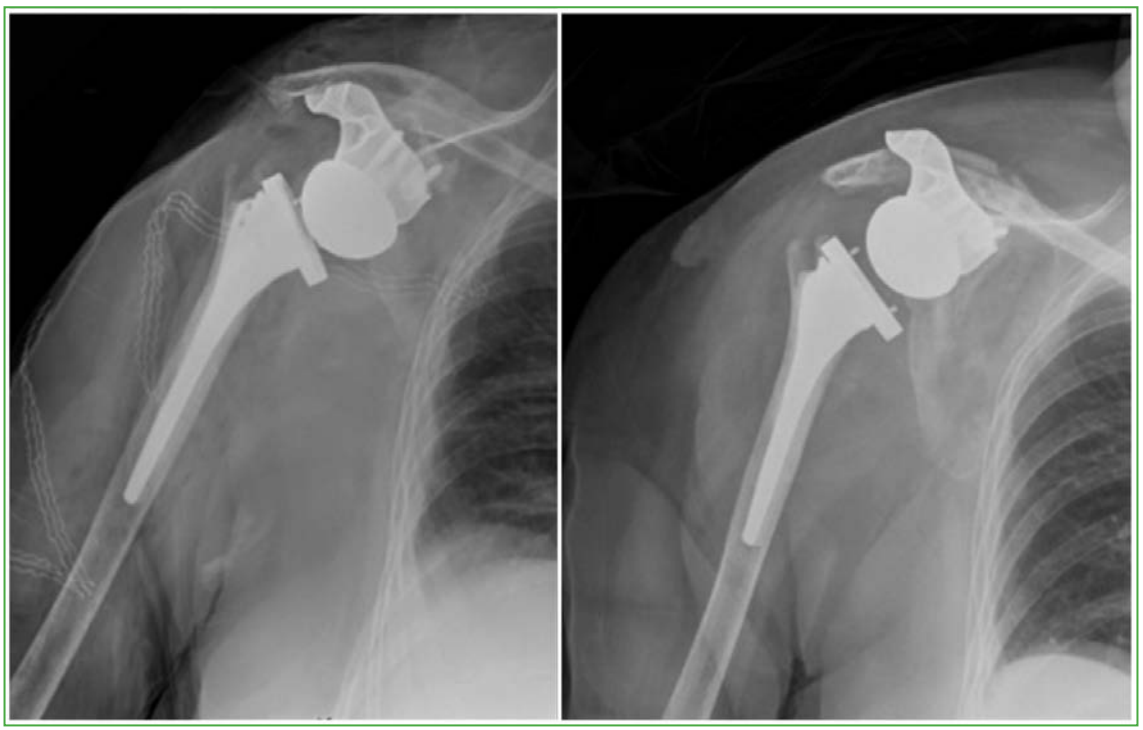

Figure 15. Radiographs of a patient with glenoid component loosening and migration, without clinical consequences.

DISCUSSION

Our results demonstrate that the use of patient-specific glenoid implants is a technically feasible option for the treatment of severe glenoid defects in revision surgery. Despite the complexity of the included cases, only one complication related to loosening of the glenoid component was observed, highlighting the stability achieved in most patients over a minimum follow-up of 12 months.

These findings are consistent with previous studies, although differences exist in patient populations and surgical indications. Chammaa et al.,[6] in a series of 37 patients, the largest reported to date, described favorable outcomes at a mean follow-up of 60 ± 25 months, with significant improvements in the Oxford Shoulder Score (from 11 to 27 points) and the Subjective Shoulder Value (from 23% to 60%). Active elevation increased from 39° ± 23° to 64° ± 38°, and external rotation from 6° ± 16° to 15° ± 17°.

However, their study focused on primary arthroplasties, whereas our series includes only revision procedures, which reinforces the relevance of our findings by demonstrating that patient-specific implants are also effective in more complex scenarios. In addition, it is important to note that the implant used in the study by Chammaa et al. was not patient-specific but rather based on a design concept similar to that of hip arthroplasty, which may limit its effectiveness compared with implants specifically designed for shoulder anatomy.

Likewise, Rangarajan et al. reported notable improvements in the Constant-Murley score (from 24.6 to 60.4) and the ASES score (from 32 to 79), as well as in range of motion, with increases in forward elevation (from 53° to 124°), abduction (from 42° to 77°), and external rotation (from 17° to 32°) in a series of 19 patients. However, that study included both primary and revision arthroplasties, resulting in a more heterogeneous cohort, which

may limit direct comparability with our findings. In the present series, patients had a mean of 1.3 prior surgeries (range 1-4), reflecting a more complex clinical scenario; nevertheless, the functional improvements observed were comparable.[11]

Bodendorfer et al. and Ortmaier et al. reported similar outcomes in terms of range of motion and function, with a minimum follow-up of 24 months, in series of 11 and 9 patients, respectively.[2,4] In the study by Bodendorfer et al., improvements were observed in forward elevation (from 95° to 150°), external rotation (from 13° to 40°), and internal rotation (from the sacrum to L3).[4] Ortmaier et al. reported improvements in the Constant-Murley score (from 10.9 to 51.7), the Subjective Shoulder Value (from 11% to 52%), and abduction (from 19° to 121°).[2] It is important to note that, in the series by Bodendorfer et al., surgeries were performed by four surgeons across three different institutions, which may have introduced variability in both technique and surgical experience.[4]

In our series, no intraoperative complications were observed. A single postoperative complication related to the glenoid component was recorded: one patient with a type 5 defect according to the Gohlke classification developed signs of baseplate loosening during follow-up. Although this rate (12.5%) is comparable to that reported in other series, studies such as that by Chammaa et al. reported a complication rate of 24% (9 of 37 patients), and Rangarajan et al. reported a rate of 21% (4 of 19 patients), including infections, hematomas, and intraoperative fractures.[6,11] Other authors, such as Porcellini et al., described minor radiographic findings and one dislocation in a series of six patients,[5] whereas Bodendorfer et al.,[4] and Ortmaier et al.[2] reported no complications. This variability may be attributable to differences in the defects treated, surgical experience, technique, and duration of follow-up.

Patient-specific glenoid implants offer several important advantages. They allow precise adaptation to complex bone defects, improving surgical accuracy and optimizing implant fixation and primary stability. This is particularly relevant in patients with severe defects in whom conventional implants may not provide an adequate solution.[2] Preoperative planning using the described methodology enables accurate assessment of bone stock and density, maximizing contact with the native glenoid and optimizing screw positioning, trajectory, and length. This results in improved primary stability and subsequent osseointegration, as observed in our series. Furthermore, the ability to design patient-specific implants allows effective management of anatomical variability and the specific characteristics of each glenoid defect.

However, this technique has certain drawbacks, such as a steep learning curve due to the low incidence of cases, which may impact operative time. In our series, variability in operative time was directly related to the type of procedure performed; although all cases involved revision arthroplasty, in two patients only the glenoid component was revised, whereas in the remaining cases both components were addressed. In cases of failed osteosynthesis, additional time required for hardware removal must be considered; similarly, failed hemiarthroplasties required removal of the humeral component, generally involving a humeral osteotomy. Another limitation is the delay between acquisition of the 3D CT scan and surgery. In our experience, once preoperative planning is approved, the implant can be manufactured and made available to the surgeon within a minimum of 5 weeks. The cost of patient-specific implants is higher than that of standard off-the-shelf implants, which may represent a limiting factor in certain settings.

This study has several limitations that should be considered. First, it is a retrospective study without a control group, which may limit interpretation of the results. Although the number of patients included is comparable to that of published international studies, the small sample size (eight patients) limits generalizability and may not capture the full variability of the population with severe glenoid defects. This small sample also precludes statistical power calculation, thereby limiting the validity of comparisons and introducing a potential risk of Type II error. Therefore, the results should be interpreted as preliminary and descriptive, and studies with larger sample sizes are required to confirm the effectiveness of patient-specific implants. In addition, the follow-up period was relatively short (12 months), precluding adequate assessment of long-term implant survival.

Furthermore, no independent evaluator was used to assess range of motion, as measurements were performed by the treating surgeon during clinical follow-up visits. Another limitation is that imaging follow-up was performed exclusively with plain radiographs in two projections (true anteroposterior and scapular axial views). Given the complex three-dimensional structure of these implants, CT evaluation could have provided more pre-

cise information regarding osseointegration; however, it was not performed due to additional costs and radiation exposure.

The novelty of this technique and its limited indications also restrict the number of patients treated with patient-specific glenoid implants to date, which further limits generalizability. Longer follow-up and larger cohorts are required to draw more robust conclusions regarding implant survival and complication rates.

Despite these limitations, this study has several notable strengths. To our knowledge, it is the first study published in a national and Latin American setting evaluating patient-specific glenoid implants with a minimum follow-up of one year, thereby providing a valuable contribution. The homogeneity of the study population is another important strength, as all patients underwent revision arthroplasty, allowing comparison with similar series. In addition, all procedures were performed by a single surgeon at a single institution, ensuring consistency in surgical technique and experience, and minimizing variability in outcomes.

CONCLUSIONS

Our study reports promising preliminary findings on the use of patient-specific glenoid implants in revision reverse shoulder arthroplasty, demonstrating positive outcomes in terms of range of motion, function, and pain reduction, with a low complication rate. Although further studies with larger cohorts and longer follow-up are required, these preliminary results support the use of this technology in patients with severe glenoid defects.

Conflicts of interest: The authors declare no conflicts of interest.

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