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Short-term outcomes of using custom 3D printed base plates in reverse shoulder arthroplasty for patients with glenoid cavity defects

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Objective. To conduct a retrospective analysis of the short-term clinical and radiographic outcomes of reverse total shoulder arthroplasty using custom glenoid base plates in patients with glenoid cavity defects. Methods. We retrospectively studied the surgical outcomes of 10 patients with defects of the glenoid cavity who underwent reverse total shoulder arthroplasty using individual glenoid base plates. The average follow-up period post-surgery was (2.6 ± 1.6) years. The mean age of the patients was (62.4 ± 5.6) years, including 7 women (70 %) and 3 men (30 %). Two patients (one woman and one man) underwent RTSA on both shoulders, resulting in a total of 12 RTSA procedures performed on 10 patients. All patients underwent shoulder joint imaging using spiral computed tomography, modeling of the individual base plate implant for the glenoid part of the endoprosthesis, and fabrication of the implant using 3D printing with titanium powder. The function of the shoulder joint was evaluated using the Constant-Murley Shoulder Score (CMS). Results. The mean cortical index was 0.38 ± 0.06. Lateralization and distalization angles were measured at 80° ± 5.6° and 55° ± 8.2°, respectively. The average active range of motion for external rotation was 60° ± 5.5°, flexion and elevation of the upper limb at the shoulder joint (including the scapula) was 135° ± 8.4°, internal rotation was 85° ± 3.4°, and abduction of the shoulder joint (including the scapula) was 145° ± 10.2°. The mean score on the CMS scale was 85. Conclusion. The retrospective analysis demonstrates a significant reduction or complete absence of pain syndrome along with improved functional outcomes in patients after RTSA with glenoid cavity defects when using custom base plates for the glenoid part of the reverse shoulder endoprosthesis. Keywords. Reverse total shoulder arthroplasty, RTSA, proximal humerus fracture, glenoid cavity defect, shoulder osteoarthritis, additive technology, 3D printing, porous titanium custom implants, Constant-Murley Score.

Мета. Провести ретроспективний аналіз короткострокових клінічних і рентгенографічних результатів зворотного ендопротезування плечового суглоба з використанням індивідуальних базових пластин у пацієнтів із дефектами суглобової западини лопатки. Методи. Вивчено результати хірургічного лікування 10 осіб із дефектами суглобової впадини лопатки, яким було проведене RTSA з використанням індивідуальних гленоїдальних базових пластин. Середній післяопераційний термін спостереження — (2,6 ± 1,6) року. Середній вік пацієнтів становив (7 жінок і 3 чоловіків) (62,4 ± 5,6) років. Двом особам (жінка та чоловік) виконано RTSA обох плечових суглобів. Отже проведено 12 RTSA 10 хворим. Усім здійснено моделювання та друк на 3D-принтері індивідуального імплантата базової пластини гленоїдальної частини ендопротеза. Функцію плечового суглоба за результатами лікування оцінювали в балах за шкалою Constant-Murley Shoulder Score (CMS). Результати. Середній кірковий індекс склав (0,38 ± 0,06). Кут латералізації склав 80° ± 5,6°, дисталізації — 55° ± 8,2°. Активний обсяг рухів зовнішньої ротації в середньому склав 60° ± 5,5°, згинання та підйому верхньої кінцівки в плечовому суглобі до переду разом із лопаткою — 135° ± 8,4°, внутрішньої ротації — 85° ± 3,4°, відведення в плечовому суглобі, разом з лопаткою — 145° ± 10,2°. Середній бал за школою CMS — 85. Висновок. Ретроспективний аналіз довів, що в пацієнтів після RTSA з дефектами гленоїдальної западини фіксується зменшення або повна відсутність больового синдрому з одночасним покращенням функціональних показників за умов використання індивідуальних базових пластин гленоїдальної частини зворотного ендопротеза плечового суглоба.

Ключові слова. Зворотне ендопротезування плечового суглоба, перелом проксимального відділу плечової кістки, дефект гленоїдальної западини, остеоартроз плечового суглоба, адитивні технології, 3D-друк, пористі титанові індивідуальні імплантати, Constant-Murley Score

Introduction

Reverse total shoulder arthroplasty (RTSA) is an effective surgical treatment for multifragmentary fractures of the proximal humerus with reduced bone mineral density and their sequelae, especially in elderly patients [1]. Over the past decades, there has been an increase in the use of RTSA worldwide, with a simultaneous increase in the number of different types of reverse shoulder arthroplasty [2]. Despite the existing experience of RTSA for 40 years, complex bone loss of the articular part of the scapula and its deformations remain a significant problem [3]. Curvatures and defects of the glenoid fossa can occur as a result of severe degenerative or post-traumatic changes, congenital anomalies, tumors, or after primary total shoulder arthroplasty. The lack of sufficient contact area with the base plate of the glenoid component of the endoprosthesis and poor bone quality lead to early instability, dysfunction, and pain [3, 4].

Various approaches have been used to address this complex issue: eccentric expansion of the glenoid cavity with burrs, bone auto- or alloplasty, the use of metal base plates with an alternative location of the central screw or metal base plates with a porous surface or augments [5]. However, clinical results with their use remain ambiguous. The high rate of complications, including implant instability and lack of its integration, prompts the search for new methods for solving the problem of defects in the scapular glenoid cavity [6].

Several literature sources have already reported satisfactory short-term clinical and radiological results of RTSA using individual implants obtained using additive technologies [4–7]. The introduction of computer modeling with subsequent 3D printing from titanium powder to create an individual base component of the glenoid cavity to replace defects is one of the promising directions for solving this issue.

Purpose: to retrospectively analyze the short-term clinical and radiographic results of reverse shoulder arthroplasty using individual base plates in patients with scapular socket defects.

Material and Methods

The retrospective study included 10 patients with scapular socket defects who underwent RTSA using individual base plates. The study was approved by the Bioethics Commission of the State Institution Professor M. I. Sytenko Institute of Spine and Joint Pathology of the National Academy of Medical Sciences of Ukraine (22.04.2019, protocol No. 191, 20.02.2023, protocol No. 229). All the patients provided written informed consent, confirming their voluntary participation and understanding of the study procedures, potential risks and benefits. The mean postoperative follow-up period was (2.6 ± 1.6) years (range 2 to 5), and the mean age of the patients was (7 women, 3 men) (62.4 ± 5.6) years (range 50 to 70). Two patients (a woman and a man) underwent RTSA of both shoulder joints. Thus, 12 RTSA were performed in 10 patients.

Surgical treatment of patients was performed in the period 2019–2025 at the City Clinical Hospital No. 16 (Dnipro, Ukraine). All patients met the following inclusion criteria:

– age not less than 50 years;

– fracture of the proximal humerus of type 11-B or 11-C according to the AO/OTA classification or its consequences [8];

– stage 3 osteoarthritis of the shoulder joint with a defect in the glenoid cavity;

– pronounced decrease in bone mineral density with a cortical index (CI) value ≤ 0.4.

In 8 patients (3 men and 5 women), the defect of the glenoid cavity was caused by post-traumatic changes, in 2 (women) by osteoarthritis of the shoulder joint.

All patients underwent a standard clinical examination and X-ray examination of the injured upper limb in the preoperative period. To identify the features of the displacement of the fragments of the glenoid cavity and defects of the glenoid cavity, all patients underwent spiral computed tomography (SCT).

The study of the shoulder joint was performed on an AQUILION spiral computed tomography (Toshiba, Japan) with the acquisition of slices for building a three-dimensional model and further modeling of an individual implant of the base plate of the glenoid part of the endoprosthesis. At the stage of cooperation with engineers, the possible dimensions of the implant, its location, directions of insertion and the number of screws for fixation were determined. A device made of sterilized plastic was also created for the correct orientation and insertion of the axial pin into the glenoid cavity. Then, according to the obtained models, implants were printed on 3D printers from titanium powder.

Features of the surgical technique

Under general anesthesia in the "beach chair" position, deltopectoral access was performed in all cases. Special attention was paid to the careful release of soft tissues from the humeral fragments and scars, both interfragmentary and between the humeral fragments and the glenoid cavity in the case of old fractures of the proximal humerus. It is mandatory to mobilize the proximal humerus so that it is possible to make a correct cut of the humeral head according to the guides, with the subsequent installation of a retractor to shift the humerus downward. Depending on the specific situation, it is possible to mobilize the deltoid muscle from the acromion. Scar tissue in the subacromial space is always carefully removed, as well as the scars that fill the glenoid cavity defect with remnants of the labrum and long head of the biceps tendon. In all cases, a 3D-printed plastic guide device was used to guide the central pin. After that, a plastic base support implant similar to the titanium one was placed on the pin to determine its orientation, location, and the need for soft tissue and bone removal (but excessive removal should be avoided). Next, a press-fit fixation of the printed porous implant was achieved using an impactor. Visual confirmation of complete placement was performed by checking the presence of clearance in the screw holes and light manual testing using a hook. The implant was tightly positioned without wobble in all cases, and for additional initial stability, fixation was performed with 3.5 mm titanium screws according to 3D planning. A diamond-like carbon (DLC) coated metal glenosphere was then placed on the Morse taper of the base plate (Fig. 1), followed by placement of the humeral component of the prosthesis and standard surgical completion. All RTSAs were performed by the same surgeon. Additional cementation of the base plate was not used in any case.

Retroversion of the prosthesis stem was 10° in 12 cases.

The rehabilitation protocol was standard. Postoperative fixation of the upper limb in all patients was performed with a Dezo bandage for 4 weeks. Passive movements in the elbow and shoulder joints were allowed for 2–3 days after surgery under the supervision of a physiotherapist instructor, active movements were allowed in 3–4 weeks. After surgery, patients had appointments for control examinations in 3, 6 and 12 months, as well as annually for radiographic evaluation in two projections.

When using standard reverse shoulder endoprostheses, lateralization and offset depend on the hemisphere and design of the shoulder component, as well as inserts. In our cases, individual three-dimensional biomechanical modeling allowed lateralization to be laid in the base plate.

Bone mineral density in all patients was assessed by radiographic images of the humerus in the anteroposterior projection with calculation of the CI [9]. The presence of a scapular neck defect was assessed according to the Nerot-Sirveaux classification [10, 11].

Fig. 1. Glenosphere covered with DLC

Lateralization and distalization were measured using the angles described by Boutsiadis et al. [12].

Radiographic characterization of signs of bone lysis around the glenoid cavity was performed according to the Souter's-Deutsch classification [13].

In 3 patients, a multifragmentary fracture of the scapula was observed as a result of trauma, simultaneously with a fracture of the glenoid cavity: type IB according to the Ideberg-Goss classification [14] in 1 patient, type II in 2. Due to the lack of surgical treatment in the first months after the trauma, a post-traumatic defect of the glenoid cavity was formed. In conclusion, we consider these cases within the concept of post-traumatic osteoarthritis of the shoulder joint with a glenoid cavity defect, which is subject to classification according to Walch [15].

Shoulder function after treatment was assessed using the Constant-Murley Shoulder Score (CMS) [16], a functional scale with a maximum total score of 100, reflecting optimal shoulder function. Treatment outcomes were assessed 3, 6, and 12 months after surgery. CMS scores for each patient were determined to the nearest integer due to the integer nature of the scale.

Statistical analysis. Quantitative assessments were defined as mean (x) ± standard error (SE). Differences between functional outcomes in CMS scores were assessed using the Tukey test at a significance level of $p < 0.05$ based on the results of one-way analysis of variance (ANOVA).

Results and Discussion

12 RTSAs were performed in 10 patients. The average postoperative follow-up period was (2.6 ± 1.6) years (from 2 to 5). At the time of the last control, none of the operated patients had complications that affected the final outcome.

The CI was determined at 0.38 ± 0.06 (0.30–0.40). Type 11-C fracture according to AO/OTA was observed in 8 patients, stage 3 osteoarthritis of the shoulder joint in 2.

According to the Walch classification of glenoid cavity defects, type B1 was observed in 2 patients, B2 in 2, and type C in 6 [15].

Lateralization and distalization [12] were noted at the following level: lateralization angle — 80° ± 5.6°, distalization — 55° ± 8.2°.

In 2 patients, radiological characteristics of signs of bone tissue lysis around the base plate showed grade II after 2 years according to the Souter's-Deutsch classification [13] without signs of functional impairment and pain syndrome.

Scapular notch, which is a specific complication of reverse shoulder arthroplasty, did not occur in any case during the observation period.

The active range of motion of external rotation was on average 60° ± 5.5°, flexion and elevation of the upper limb in the shoulder joint to the front together with the scapula 135° ± 8.4°, internal rotation 85° ± 3.4°, abduction in the shoulder joint, together with the scapula 145° ± 10.2°. All patients are satisfied with the result of the operation. The average CMS score was 85.

Clinical case

A 60-year-old patient C. was admitted to the polytrauma department of the CNE CCH No. 16 DCC with a diagnosis of old fracture dislocation of the right and left shoulder joints with pronounced adductor contracture and pain syndrome (AO / OTA 11-C3, CI = 0.3), 2 months after injury, Walch type C defect of the articular surface of the glenoid cavity (Fig. 3, 4).

According to the SCT, both individual design of plastic 3D conductors for the axial pin and individual modeling and manufacturing of a porous glenoid support plate for the hemisphere of the Evolutis endoprosthesis were performed (Fig. 5, 6).

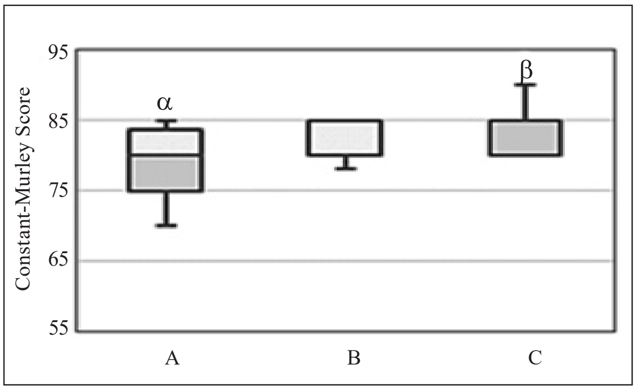

Fig. 2. Dynamics of changes in functional results of patients according to mean CMS scores 3 (A), 6 (B) and 12 (C) months after surgery; upper and lower borders of the rectangle are lines of 25 and 75% quartiles; horizontal line inside the rectangle is the median; dark and light color indicate 50 and 75 % quartiles, respectively; borders of vertical lines are minimum and maximum values; different letters indicate results with statistically significant ($p < 0.05$) differences

Under general and conductive anesthesia, patient S. underwent the following first stage: primary total hybrid reversible arthroplasty of the right shoulder joint with an individual porous titanium support 3D plate, taking into account the replacement of glenoid cavity defects (Fig. 7, 8).

Immobilization with a Dezo bandage lasted 4 weeks. Passive movements in the shoulder joint under the control of a physical therapy instructor were started on the 1st week after the operation, active ones in 4 weeks. The function of the right shoulder joint was restored: the Constant-Murley index 3 months after the operation was 80 points, and 85 points in 6 months (Fig. 8).

At the second stage, after 8 months, under general and local anesthesia, patient S. underwent primary total hybrid reversible endoprosthesis of the left shoulder joint Evolutis with an individual porous titanium support 3D plate, taking into account the replacement of defects in the glenoid cavity (Fig. 9–12).

The use of 3D modeling, considering the defect of the glenoid articular surface and the creation of an individual glenoid part of the reversible endoprosthesis of the humerus from trabecular titanium, allowed obtaining an excellent stable result, namely 85 points according to the Constant-Murley Shoulder Score system.

The superiority of RTSA over conservative treatment in very elderly patients (over 80 years) with varus posteromedial and valgus impact fractures is not clearly proven [17]. At the same time, in patients under 80 years of age, RTSA has shown its superiority in functional outcomes compared with conservative treatment and hemiarthroplasty in most studies. Recent observations also demonstrate the superiority of RTSA over open reduction and internal fixation in patients over 60 years of age [18]. Most authors recommend performing RTSA in the acute phase after a proximal humerus injury, although some studies have not found a significant difference compared with performing RTSA in the delayed period after the injury [19].

Reverse shoulder arthroplasty has become a successful surgical solution for many patients with proximal humerus fractures. The benefits of RTSA are recognized for fractures with severe head involvement, but are not as evident for borderline varus posteromedial and valgus fractures [20].

Current RTSA base plate designs have a low failure rate, but further analysis is needed in the setting of glenoid fossa defects to determine whether

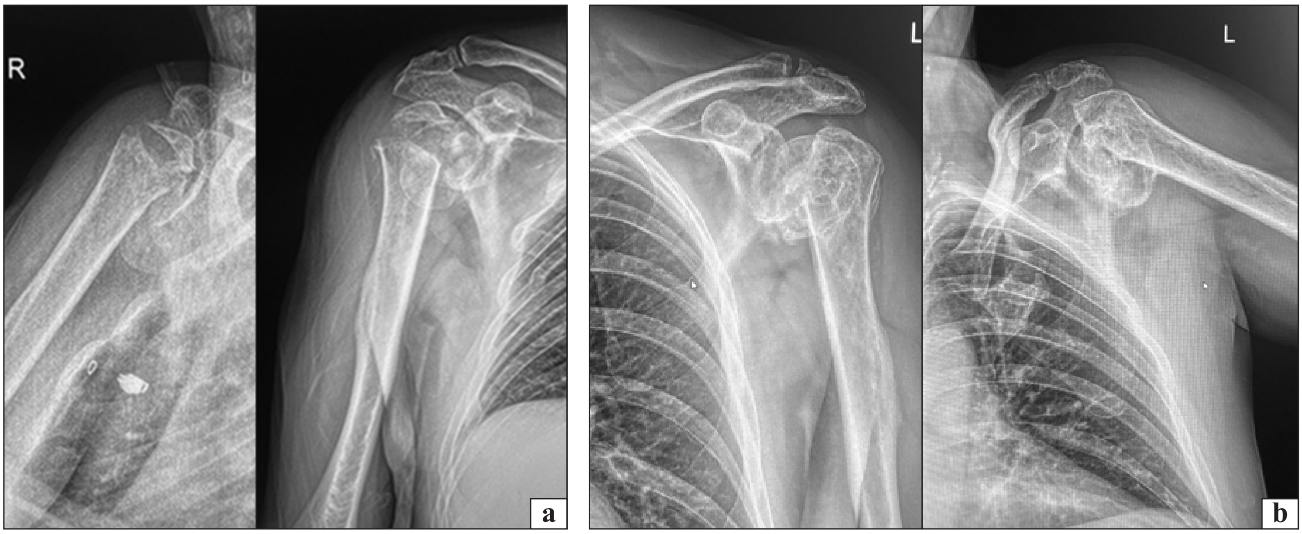

Fig. 3. Radiographic images of patient C., 60 years old, 11-C3, 2 months after injury, defect of the articular surface of the glenoid cavity of the right (a) and left (b) shoulder joints

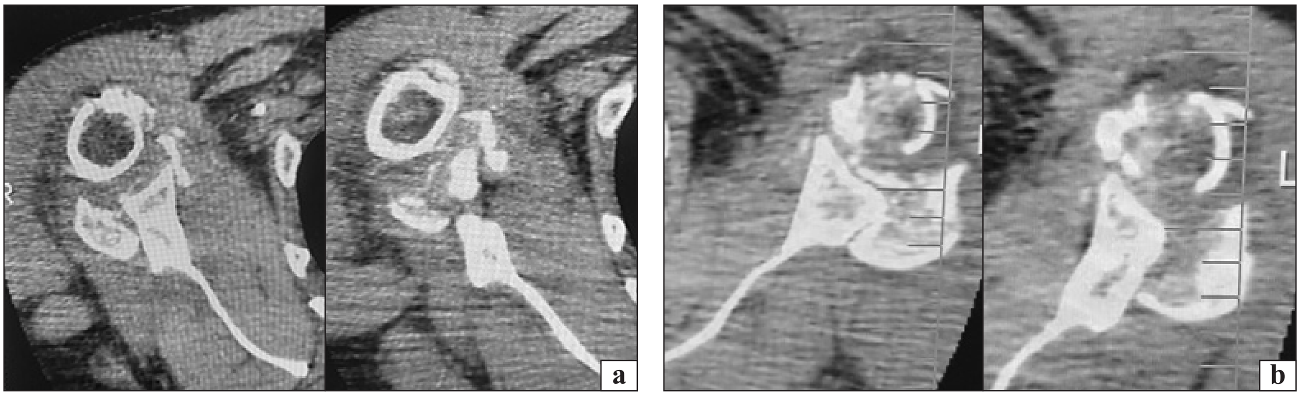

Fig. 4. Photo of CT scans of patient C., 60 years old, 11-C3, 2 months after injury, defect of the articular surface of the glenoid cavity of the right (a) and left (b) shoulder joints

the degree of feasibility is critical or whether custom 3D-printed glenoid augments or base plates are preferable [21].

Early designs of reverse total shoulder arthroplasty demonstrated high rates of complications and reoperations related to the standard glenoid baseplate design. Although modern versions of the arthroplasty have reduced the failure rate, an increased risk of complications has been reported for RTSA when bone grafts are used to replace glenoid socket defects during the first two years after surgery [22].

Several studies [23, 24] have shown that clinically significant improvements, as reported by patients and measured by scales, after RTSA in the case of glenoid socket defects and the use of custom baseplates are only observed one year after surgery. This makes our observations valid for comparison.

The anatomic and functional improvement rates we obtained are consistent with those of previous studies that used custom implants to correct glenoid socket bone deficiencies after RTSA [25].

Today, the implantation of the base plate after RTSA remains a challenge and is technically difficult even for an experienced surgeon. Instability of the glenoid component is one of the common reasons for revision shoulder arthroplasty [22–25]. Therefore, we consider it appropriate to use individual base plates of the glenoid part of the reverse shoulder arthroplasty in case of defects in the bone tissue of the articular process of the scapula. Our observations indicate a decrease or complete absence of pain syndrome in patients after RTSA with a simultaneous increase in functional results. Thus, a significant increase in the volume of active movements and an improvement in the quality of life due to the full use of the upper limb in daily life was recorded.

This retrospective study is limited by a small patient sample and short follow-up; longer observation is needed to assess implant stability over time.

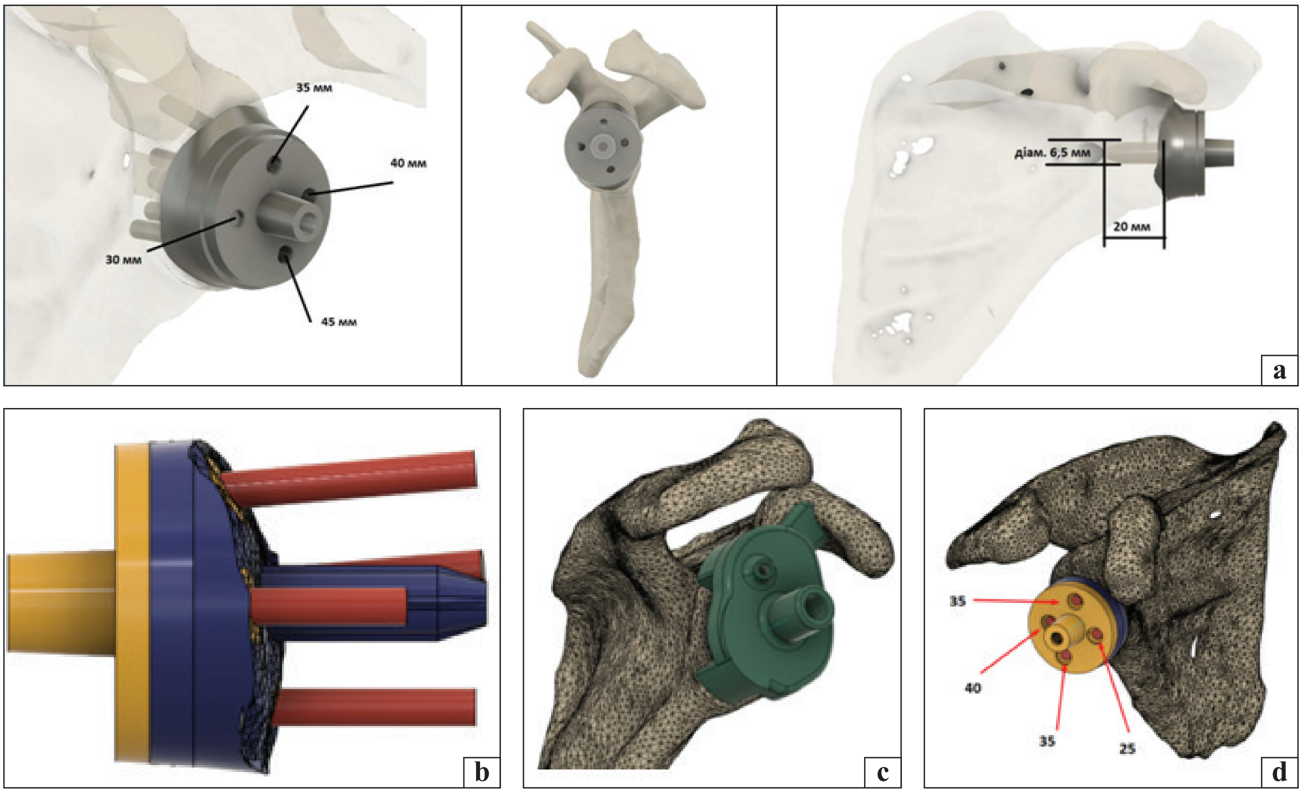

Fig. 5. Stages of modeling in the presence of a glenoid cavity defect: multi-projection image of the glenoid base plate (a); Custom modeling and manufacturing of a porous glenoid base plate for the hemisphere of the Evolutis endoprosthesis (b); computer 3D model with a conductor for the axial wire (c) and the glenoid base plate for the hemisphere of the Evolutis endoprosthesis taking into account the replacement of defects (d)

Fig. 6. Plastic printed model of the developed glenoid base plate taking into account the defects of the glenoid cavity of the scapula on the right

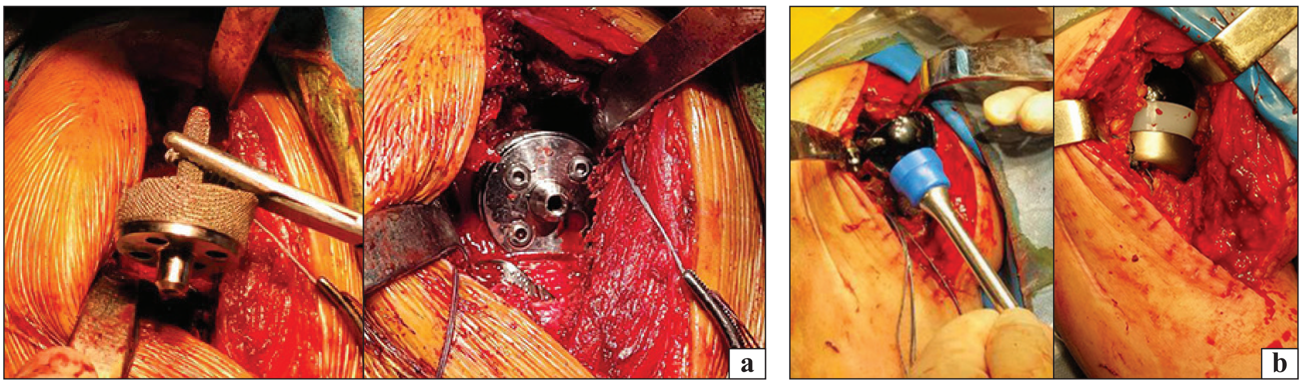

Fig. 7. Stage and surgical treatment of patient S.: implantation of a 3D glenoid support plate (a) and its appearance in the surgical wound (b)

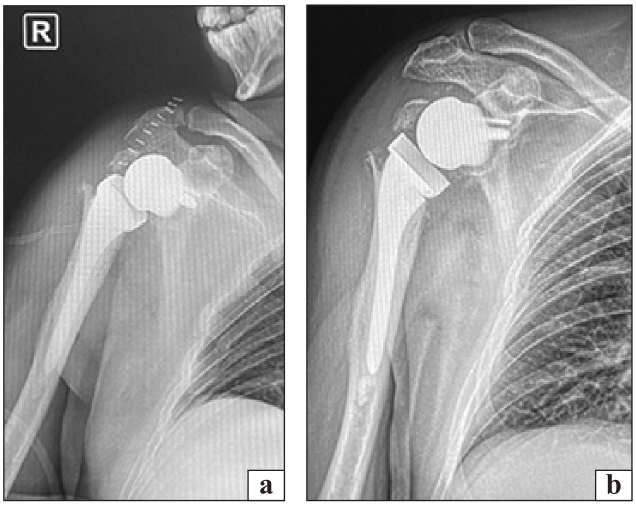

Fig. 8. Radiographic images of patient S. immediately (a) and 3 months (b) after surgery

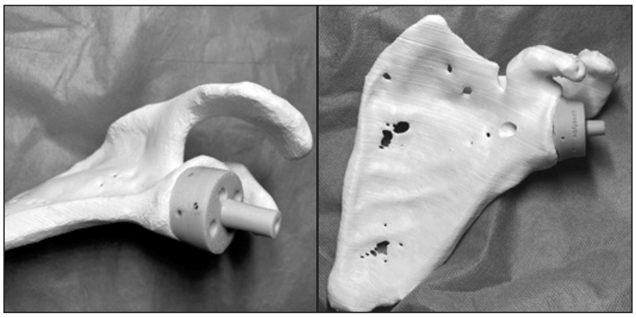

Fig. 9. Plastic printed model of the developed glenoid support plate taking into account defects in the glenoid cavity of the left scapula

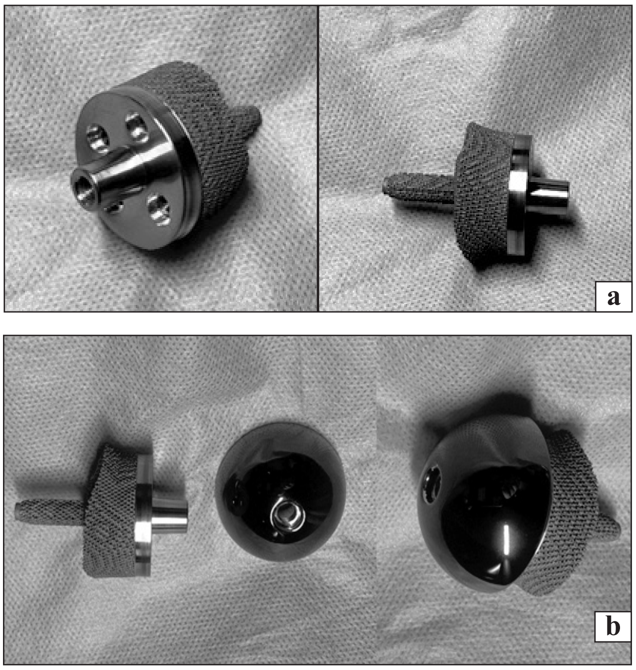

Fig. 10. Printed titanium porous base individual glenoid plate taking into account defects (a); glenoid plate with a glenosphere covered with a diamond-like carbon (DLC) (b)

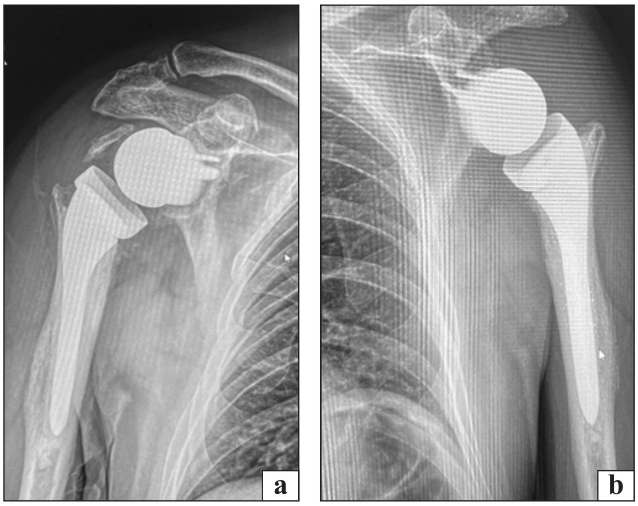

Fig. 11. Radiographic images of the right (a) and left (b) shoulder joints of patient S. 2 years after surgery — complete osseointegration without signs of lysis

Fig. 12. Photo of patient S. 2 years after RTSA — functional outcome

Conflict of interest. The authors declare the absence of a conflict of interest.

Prospects for further research. Promising are studies on the analysis of osseointegration of individual titanium porous structures printed on a 3D printer and the study of long-term results after reverse shoulder arthroplasty.

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Authors' contribution. Makarov V. B. — concept and design, collection and processing of materials, analysis of the obtained data, drafting the article; Korzh M. O. — concept, drafting the article, editing the text.

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SHORT-TERM OUTCOMES OF USING CUSTOM 3D PRINTED BASE PLATES IN REVERSE SHOULDER ARTHROPLASTY FOR PATIENTS WITH GLENOID CAVITY DEFECTS

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