Annals of Medicine and Medical Sciences (AMMS)
Volume 02, Issue 01, Jan-Feb 2023,
Available at: *www.ammspub.com*

Review article

Glenoid Bony Deficiency in Shoulder Arthroplasty, Management Options

Amr Elshahhat

Lecturer of Orthopedic Surgery, Mansoura University, Egypt.

*Corresponding author: Amr Elshahhat; *amrelshahhat@mans.edu.eg*

Abstract

Glenoid bone deficiency usually represents a technical challenge for orthopedic surgeons. It is often associated with a higher complication rate and inferior clinical outcomes following shoulder arthroplasty. This paper represents a narrative review for classification systems of wear patterns and management options to compensate for the bony loss. Additionally, the merits and outcomings of each option.

Keywords: Glenoid, wear, shoulder arthroplasty, eccentric reaming, bone grafting

Introduction

Glenoid wear is often associated with degenerative and inflammatory osteoarthritis (OA), rotator cuff arthropathy (RCA), post-traumatic arthrosis, and chronic dislocations. Each disease has its characteristic associated wear pattern; central wear occurs in inflammatory arthropathy, superior wear in RCA, and massive anterior or posterior wear in chronic dislocation. Nonetheless, combined wear patterns might occur in OA represented in combined posterior and inferior deficiency [1]. Bony deficiency represents a challenge to operating surgeon especially cavitary and segmental defects [2-4]. This article aims at reviewing classification systems and management options of glenoid wear.

Classification systems

Many classification systems have evolved to address glenoid bony deficiency based upon radiographs and computed tomography (CT). *Walch et al.* [5] classification relied upon the glenoid version presented on axillary radiographs to detect glenoid wear in primary OA (**Figure 1**). **A:** Central erosion (59%): The humeral head is centered over glenoid. (**A1:** minor; **A2:** severe with the head protruded into glenoid cavity). **B:** Posterior humeral subluxation (32%): (**B1:** posterior joint space is narrowed, **B2:** severe posterior erosion with biconcave glenoid appearance). **C:** > 25° retroversion regardless the erosion (9%): dysplastic origin, mostly congenital, with the head centered or in minimal posterior subluxation. They did not report clinical correlation with their classification, nonetheless, it was fruitful in surgical planning.

Later, *Bercik et al*. modified the original Walch system [6] by adding types B3 and D glenoids, in addition to a more confined definition for A2-type (**Figure 1**). The **B3-glenoid** (monoconcave) shows posterior wear with ≥ 15° retroversion or ≥ posterior humeral head subluxation, or both. The B1-glenoid differs from B3-glenoid with posterior subluxation alone by the associated posterior wear. The **D-glenoid** represents anterior humeral subluxation < 40% or glenoid with any level of anteversion. The A2-glenoid necessitates the antero-posterior (AP) glenoid plane to pass through the humeral head, unlike, A1-glenoid in which the AP glenoid line does not transect it. The Bercik modification utilized three-dimensional (3D) technology to obtain corrected 2D slices in the scapular plane. Thus, a precise version and subluxation assessments were available.

The Superior-inferior bone loss can be addressed following the *Habermeyer et al*. classification depending upon the inferior glenoid tilt. This classification (**Figure 2**) revealed the inclination of a line connecting the superior to inferior glenoid rims, to a to a vertical line through the coracoid [7]. Four types were demonstrated: **Type 0** (13%) with parallel lines, **Type 1** (16%) with intersecting lines sub-glenoid, **Type 2** (54%) intersecting at glenoid level, and **Type 3** (17%) intersecting above coracoid.

The superior glenoid wear was also described by *Sirveaux et al*. [8] with humeral superior migration after the loss of restraint to this superior migration as in RCA. *Favard et al*. [9] demonstrated four wear types (**Figure 3**): **E0** (49%): superior migration with no erosion, **E1** (35%): Concentric erosion, **E2** (10%): Superior erosion, and **E3** (6%) with progress to inferior erosion. The former classifications address glenoid wear in one plane. Nearly half of RCA-patients are often represented with combined wear in more than one plane. Correction of glenoid alignment in different planes is important, hence, this deficiency in different plane should be addressed [10].

Hamada et al. declared a five-grade classification system (**Figure 4**), by analysing the radiographic findings in massive RC tears (RCTs). **Grade 1** shows the acromiohumeral distance (AHI) being ≥ 6mm, while declined ≤ 5mm in **Grade 2. Grade 3** means grade 2 with superadded acetabulization (subacromial arthritis with concave deformity of acromial under surface). **Grade 4** is described as grade 3 associated with glenohumeral (GH) joint narrowing, and **Grade 5** shows humeral head collapse [11]. Later, *Walch et al.* identified patients with massive RCT showing GH narrowing without acromial acetabulization. consequently, grade 4 was further subdivided into grade 4A showing GH arthritis without acetabulization, and Grade 4B showing arthritis with acetabulization mimicking grade 4 Hamada *et al.* [12]. This modification could allow for more patient specification with precise classification of all injured patients [13].

Glenoid insufficiency in RC deficiency can be classified after the *Frankle et al. system* [14] into normal and abnormal

Received: December 07, 2022; **Revised:** February 02, 2023; **Accepted:** February 08, 2023

(**Figure 5**); including four subgroups; posterior, superior, global, and anterior erosions. Differentiating between normal and abnormal glenoids was sufficiently based upon radiographs and 2D-CT. Nonetheless, classifying abnormal glenoid often necessitated 3D-CT reconstruction models. Assessing a 3D-bony loss in 2D-CT is always limited [10].

Intraoperatively, glenoid bone deficiency can be identified during revision surgeries utilizing *Antuna et al. classification* [15]. As in **figure 6**, it is based upon the area of bone loss (central, peripheral, or combined) and the severity of loss (mild, moderate, and severe). In the same context, *Page et al.* [16] introduced a classification system to facilitate graft impaction in revision surgeries. This classification included: **Type 1:** contained (intact glenoid rim and vault wall), **Type 2:** uncontained but can be corrected to containable (intact rim but a vault perforation), and **Type 3:** uncontainable (deficient rim and vault). Subsequently, each type is subclassified whether bone deficiency in each variable is less or more than half of glenoid bone stock. Type 1 can be restored by cancellous bone graft impaction. Type 3 cannot be rectified via impaction grafting. Type 2A necessitates a mixture of cortical and cancellous bone graft; cortical bone is important to create a contained space through which it can accommodate the cancellous graft. Type 2B need a mesh or augment to add more stability and allow the impaction of cancellous bone graft.

A modified classification system was proposed by **Antuna and Seebauer** documenting all glenoid wear patterns. It describes defects as centric (C), eccentric (E), and combined defect (E/C). each is subclassified according destruction degree from 1 to 4 corresponding minimal, <30%, 30-60%, and >60%, additionally as per the location (anterior, posterior, etc.) [17].

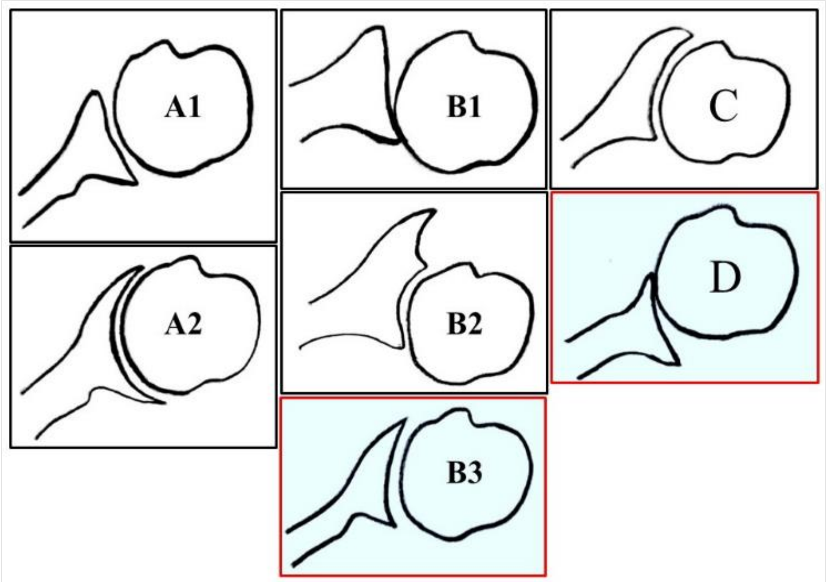

Fig. 1: The morphological glenoid classifications by Walch et al. (black bordered squares), and the modified Walch classification of Bercik (by adding two more types (red bordered squares)

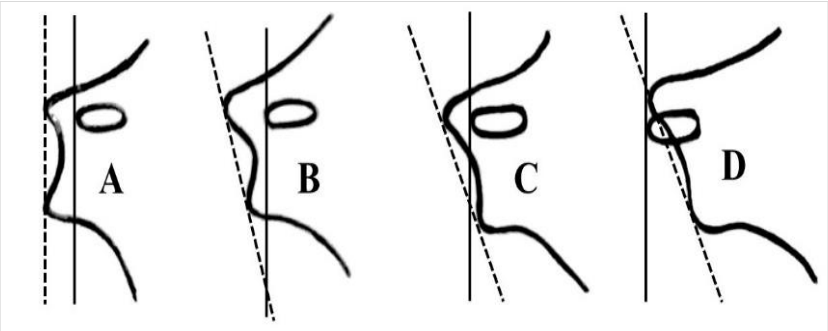

Fig. 2: The four different types of Habermeyer classification for supero-inferior glenoid inclination

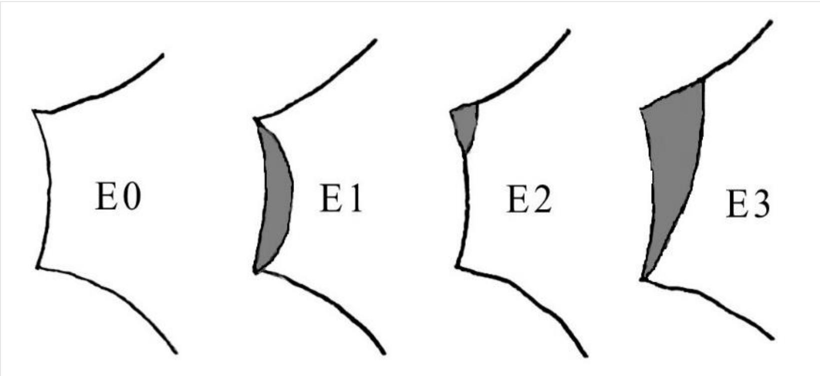

Fig. 3: Sirveaux-Favard classification for supero-inferior glenoid tilt representing glenoid wear in coronal plane (grey shaded areas represent the wear areas in different grades

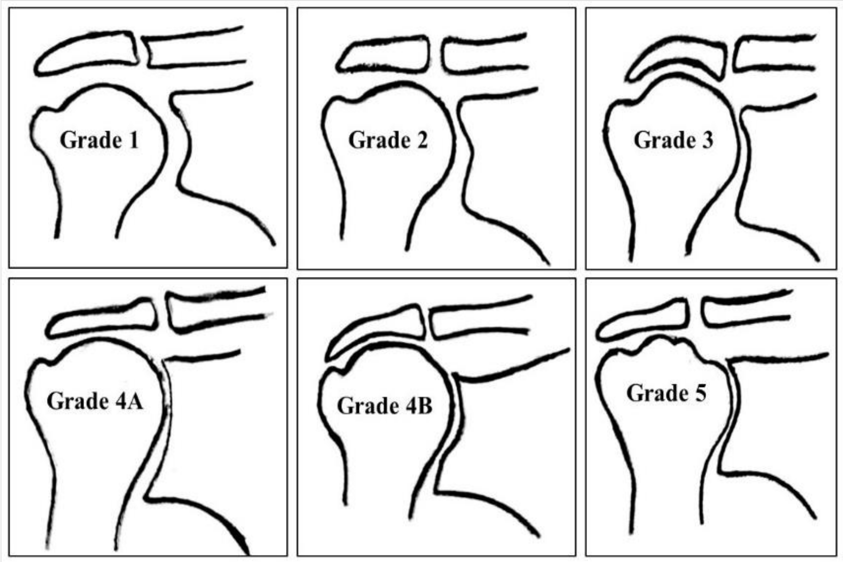

Fig. 4: The five grades Hamada et al. classification of glenoid deficiency, and the Walch modification by differentiating type 4 into 4A and 4B as per the subacromial acetabulization

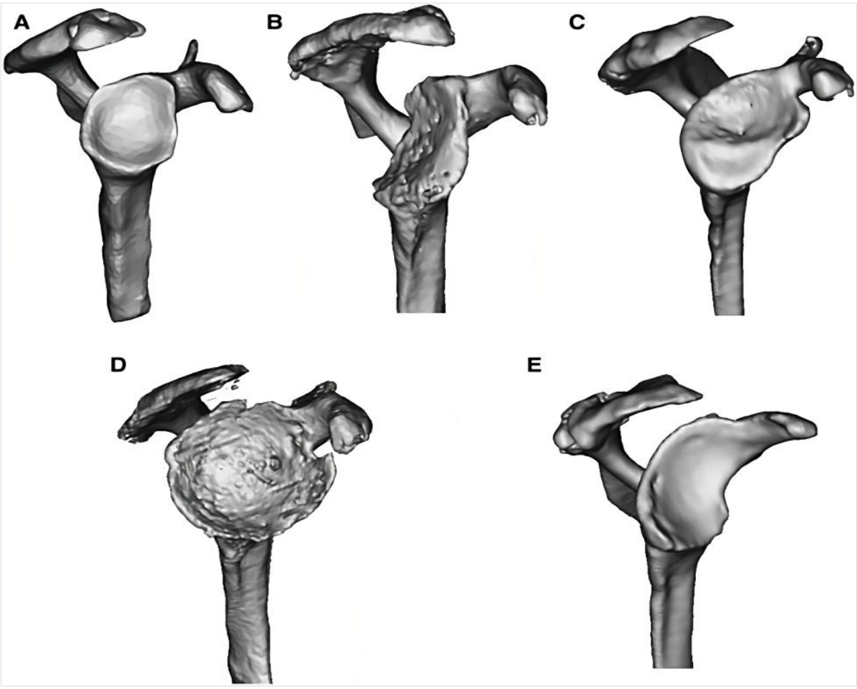

Fig. 5. Frankle classification of glenoid morphology [14]

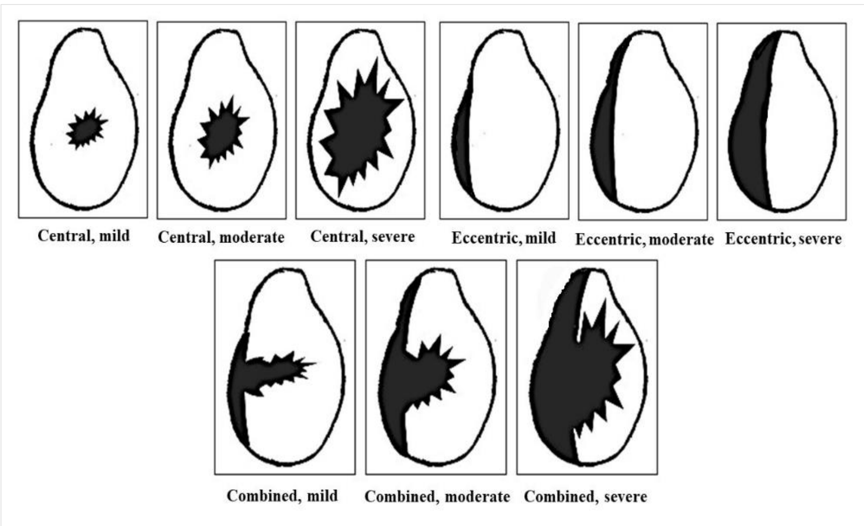

Fig. 6: Antuna classification of glenoid deficiency during revision arthroplasty after component removal

Management options

A- Hemiarthroplasty

Hemiarthroplasty was demonstrated alone or in combination with the **ream-and-run** technique for management of osteoarthritis with B2-glenoid, specifically, in active young patients, or cases with non-sufficient glenoid bone stock that cannot easily accommodate the glenoid component [18]. The rean-and-run means concentric reaming of the glenoid bone to spherical concavity with a diameter of curvature 2mm greater than that of the prosthetic humeral head [19]. This can preserve more glenoid bone without version alteration [20]. This technique necessitates anatomic designed arthroplasty without joint overstuffing, without al, painful wear continues in the face of hemiarthroplasty [21]. Soft tissue resurfacing either with fascia lata or achilles allograft, might follow ream-and-run [22], however, the long-term results are still unknown [23].

This management option was reported in literature with mixed results. *Clinton et al.* [24] compared it to TSA, and demonstrated a similar functional recovery, however, its recovery time may be longer. *Levine et al.* documented inferior results in posterior wear [25], and 14% revision rate was reported by *Gilmer et al*. [26], similarly, early progressive medial and posterior glenoid erosion was documented by *Lynch et al.* [27] at early follow-up. Hence, hemiarthroplasty alone or with ream-and-run in B2-glenoids should be used with caution.

Hemiarthroplasty remains a suitable option in complex and revision occasions where glenoid component implantation is not an option. It is also valuable as a salvage option in chronic instability following a reverse prosthesis [10].

B- Total Shoulder Arthroplasty (TSA)

TSA for B2-glenoid wear may encounter some challenges including posterior humeral subluxation, tight anterior capsule, and lax posterior capsule. Thus, soft tissue balancing remains the main target. A balanced reconstructed shoulder necessitates an appropriate glenoid version and lateralization. Many techniques were proposed including asymmetric (eccentric) reaming, bone graft augmentation, and the use of augmented glenoid component [18,28].

I- Eccentric (asymmetric) reaming

In this technique (**Figure 7**), the anterior glenoid region (high side) is reamed whilst little or none is removed from the glenoid posteriorly (worn side). There are no clear guidelines regards the amount of erosion that can safely be corrected utilizing this method. It might be efficient in deficiency ≤ 5-8 mm or retroversion ≤ 15° [29]. These reaming limits were reported following many cadaveric and simulated models [30,31].

While reaming, surgeon's goal should be achieving neutral glenoid surface mimicking posterior glenoid-surface-congruence, without over-medialization of glenoid component [32]. *Hendel et al.* recommended the use of burr to down-side the anterior glenoid for more bone preservation, thus eccentric reaming would be much easier. They followed a concept of <1cm reaming and <20° retroversion [18].

Outcome of asymmetric reaming with TSA showed mixed results. *Walch et al.* [33] reported high rates of complications with early glenoid component failure and radiolucency in treatment of biconcave glenoid. Similarly, peg penetration in most glenoids was evident in a cadaveric study done by *Gillespie et al.* [30] to correct >10° retroverted glenoids. On contrary, *Orvets et al.* [34] reported good clinical outcomes after a mean of 50 months, with no revisions due to loosening or instability. In the same context, posterior humeral subluxation was corrected and soft tissue balancing was reported by *Gerber et al*. [35] and *Habermeyer et al*. [36].

However, this technique seems to be an easy effective, it is not without disadvantages. Excessive medialization can occur when correcting glenoid defects >10 mm or retroversion >15°. This may increase the potential for glenoid vault penetration by baseplate keel [37]. Also, the glenoid vault is narrowed post-reaming, the posterior cortical support for baseplate is declined, with risk incline for glenoid loosening and subsidence. Additionally, the remained region shows a smaller interface surface area, which only permits smaller sized baseplates with risk of possible component mismatch with humeral component [38]. Moreover, excessive medialization might damage posterior capsulo-labral attachments, and lead to RC slackening and under-tension, ending with decreased stability of the reconstructed shoulder [28].

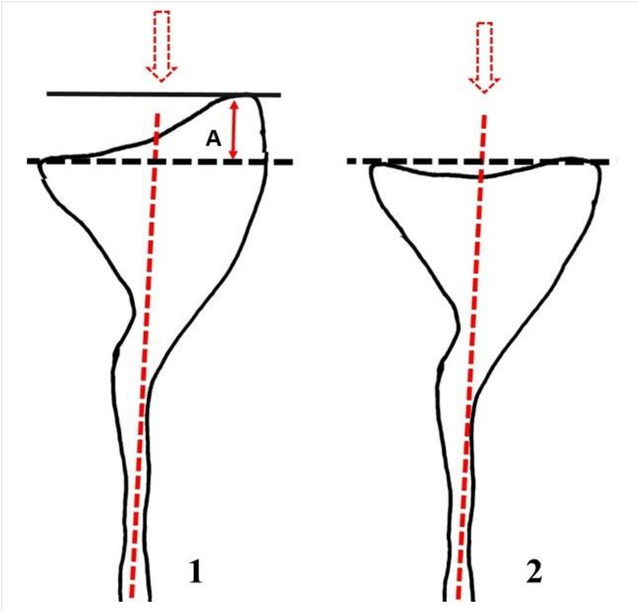

Fig. 7: The eccentric reaming technique; (A) represents the reamed depth till the level of dashed black line. The red dashed arrows demonstrate the direction of reaming in figure 7-1 and direction of baseplate implantation in figure 7-2

II- Bone Graft Augmentation

Bone grafting is always reserved for bony deficiency not amenable for correction via eccentric reaming alone. *Hill et al*. has defined three criteria for glenoid insufficiency. When one of the three criteria is met, bone grafting is indicated for baseplate fixation. The criteria are cortical penetration of the glenoid neck by the component keel or peg, incomplete peripheral contact of the glenoid component flange, or >20° of retroversion or anteversion of the component surface with complete seating [39].

The resected humeral head provides the best source for cortico-cancellous graft. Initially, bone defect is assessed and measured, followed by reaming the glenoid anteriorly to create an even flat surface, additionally, the posterior glenoid surface is burred to create a bleeding surface for better graft incorporation. The graft is fashioned and contoured to the defect, placed flush with anterior glenoid surface, and fixed by screws. Afterwards, the glenoid baseplate is implanted [18]. The optimal graft choice remains controversial, however, graft healing and incorporation within remaining glenoid remain the main concern. Allograft has generously been introduced to decrease the risk of donor-site morbidity, nonetheless, the potential risk of disease transmission still exists [40].

Outcome of bone grafting in combination with TSA was widely reported. *Neer and Morrison* [31] demonstrated excellent results at a mean follow-up of 52 months. Also, *Steinmann and Cofield* [41] reported satisfactory results at a mean of 5 years follow-up. *Sabesan et al*. [42] utilized a trapezoidal-fashioned bone graft over a step-cut glenoid, with excellent outcome in 10 of total 12 patients, and two patients required revision at a mean of 4.4 years' follow-up. Aside, worse results were elaborated by *Walch et al*. [43]

at a minimum follow-up of 2 years. A 29% failure rate was reported by *Hill and Norris* [39] at a mean of 70 months follow-up.

Appropriate graft healing was reported in different studies after midterm and long-term follow-ups [31,39, 41]. On contrary, healing defect was shown in nearly 50% of cases in some reports, however, their shoulders are functioning well and asymptomatic [41,44,45].

III- Augmented and custom-made glenoid Component

Augmented glenoid component have evolved to solve problems encountered with bone grafting technique (graft incorporation and lucency-related problems), and with eccentric reaming technique (over-medialization risk). This new design offers a more practical easier solution with the advantage of defect-filling and better bony incorporation without excessive medialization [46].

The initial designs of augmented baseplate were followed with a high failure rate and were recalled from market. The modern design with all-polyethylene component holds promise [47]. Augmented baseplates might increase stability and reduce the risk of loosening. However, only short-term results are available in literature [29]. *Rice et al*. reported unsatisfactory results of posteriorly-augmented-glenoid with mean 5-year-follow-up [48].

Currently, there is no evidence in the literature to support the use of custom-made glenoid implant. Nonetheless, its main indications are represented in compensation of posterior glenoid loss without violating remaining bone stock, secondly, a destructed glenoid vault that cannot accommodate metaglene implantation [10]. *Gunther and Lynch* [49] reported utilization of custom-made glenoid implants in seven patients with severely medialized glenoids. Also, *Sandow et al*. [50] utilized trabecular metal augmented-glenoid in ten patients who showed good implant integration at 2-years follow-up.

C- Reverse Total Shoulder Arthroplasty (RSA)

RSA has been recently introduced as a solution for B2-glenoid in patients with intact RC, with reliance on the semi-constrained design with the inherent stability of the implant design, besides, correction of associated posterior humeral subluxation [51]. When compared to TSA with grafting, RSA represents an easier solution. A more rigid fixation construct is often obtained via the added screws or the keel within the baseplate, depending upon remaining bone stock. RSA is less dependent on AP soft tissue balance, and more tolerant to retroversion. *Mizuno et al*. reported significant improvement in clinical outcome at five-years follow-up period in primary GH OA and biconcave glenoid, without posterior instability recurrence [52].

A severe glenoid bone loss that cannot accommodate for the glenoid base plate of reversed prosthesis is considered a commonly cited contraindication [53]. RSA Can be also combined with the forementioned asymmetric reaming technique and/or bone grafting from humeral head, iliac crest, or allograft. This combination can favour precise baseplate positioning. Bone grafting in primary RSA is not widely reported, however, short-term results have been encouraging, and remains the recommended technique for glenoid wear with RSA [54-56].

Klein et al. [54] managed 21 shoulders with humeral head autografts and one case with femoral head allograft, and demonstrated neither radiolucency nor implant failure. *Werner et al*. [57] reported 9.5% graft resorption and baseplate loosening after humeral head autografting in 21 shoulders at a mean of 4.9 years follow-up. Also, *Boileau et al*. [58] documented a 98% incorporation rate, with no loosening or revisions with 28 months-follow-up. *Similarly, Lopiz et al*. [59] reported 95% incorporation through a mid-term follow-up using humeral head autograft or autograft from femoral head or tibia.

Jones et al. [60] compared autograft to autograft for a severe bony defect during primary and revision RSA. They showed full graft incorporation with autograft in 51.7% of cases, and with allograft in 41.7% of cases. All patients demonstrated significant clinical improvement; however, no significant clinical differences were reported between graft types. *Bateman and Donald* [40] advocated hybrid grafting using an allograft femoral neck with cancellous autograft. Full graft incorporation was achieved by six months. No loosening or implant failures were documented after one year follow-up.

RSA provides a more favourable environment for graft incorporation compared with TSA. The graft can be compressed precisely with the screws within baseplate itself, in addition to the possible utilization of a long peg into the native glenoid [60]. The merits of bone grafting include reaching a balanced lateralized reconstructed shoulder with glenoid bone stock reservation. Outcomings represent the technical challenge, graft resorption, and glenoid component loosening with secondary failure [60].

Bony increased-offset RSA (BIO-RSA)

Boileau et al. proposed the BIO-technique (**Figure 8**), to limit the incidence of scapular notching after RSA. The offset is reconstructed utilizing a circular fashioned graft, with a central opening through which the peg passes, subsequently, stabilized via the metaglene screws adding more compression. This technique provides the flexibility to reconstruct multiplanar deformity to correct baseplate version and inclination. So, the implant–bone interface can be lateralized. They demonstrated full graft incorporation in 98% of patients [61]. These results mimicked those with RSA in revision settings with no graft failure at 2-year follow-up [55].

Malhas et al. [10] adopted the same graft technique but without necessarily lateralizing the joint line. An autologous bone graft–implant composite technique was utilized for primary and revision procedures (56 cases). They demonstrated 95% peg integration rate and 90% graft integration rate. These high integration rates were related to compressive forces applied by the metal baseplate itself, and the use of trabecular metal that possesses excellent osseo-integrative properties [62].

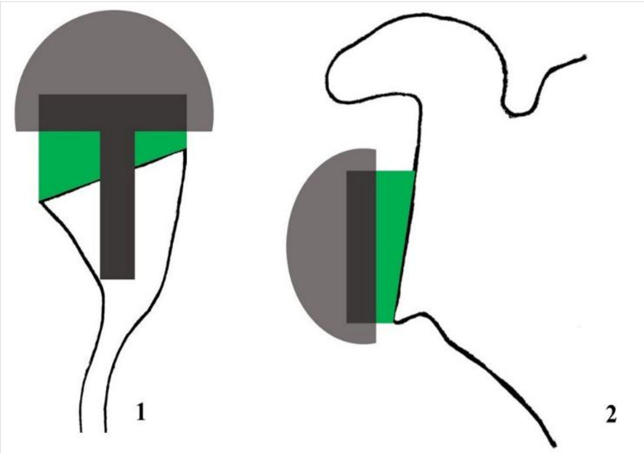

Fig. 8: The BIO-RSA technique; as shown in 8-1 and 8-2, a trapezoidal shaped bone graft (green) is fashioned after it passed through the long peg of metaglene (dark grey) to be implanted and subsequently fixed and compressed with screws inside the metaglene. Finally, the glenosphere (light grey) is inserted

Special considerations

- **Revision shoulder arthroplasty**

Revision-RSA might be linked to inferior outcomes when compared to primary-RSA. The glenoid bone stock is always deficient after primary arthroplasty, this hinders baseplate fixation with risk-incline for loosening and failure [37,63].

Available studies exist concerning the use of cortico-cancellous bone grafting in revision arthroplasty, either by iliac crest autograft or allograft, or mixed [64]. *Elhassan et al*. [65] reported the short-term result after TSA conversion to RSA or revision through introducing cortico-cancellous or femoral head allograft in revision with TSA. They reported well fixed, properly seated glenoid component, in addition to good functional outcome. Similarly, *Walker et al*. [66] reported improved outcomes using RSA with femoral head allografting for revision of failed TSA. Patients showed graft incorporation at final follow-up. *Holcomb et al*. [63] also reported four cases of revision RSA for failed glenoid component utilizing cortico-cancellous allograft via iliac crest or femoral head. *Neyton et al*. [55] showed mixed clinical outcomes, however, there was neither graft failure nor glenoid component failure. *Kelly et al*. [67] demonstrated graft incorporation in all patients with utilizing iliac crest autograft at 34 months follow-up period.

On contrary, *Wagner et al*. [68] reported 23% graft resorption with different graft sources either autografts, allografts, or mixed grafts with 3.1 years-follow-up. *Also, Melis et al*. [69] reported failed RSA in three out of 29 cases of failed TSA required revision with RSA and grafting. Structural iliac crest or cancellous autograft, or allografts were used, they reported 76% total incorporation rate of the utilized grafts, and they did not differentiate the results of allografts compared with autografts.

- **Neglected shoulder dislocation**

Werner et al. [57] reported improved functional outcome at final follow-up after RSA for chronic anterior shoulder dislocation with severe anterior glenoid deficiency. Glenoid loss was compensated with the resected humeral head autograft, however, two out of 21 patients experienced graft failure.

- **Type C glenoid**

Type C glenoids can be differentiated as per humeral head relation into: type C1 without posterior humeral subluxation, and type C2 with posterior subluxation and biconcave configuration [70]. *Mori et al.* [71] postulated that humeral head recentring over the native glenoid surface should be aimed without the necessity to correct the version to neutral. Thus, internal rotation could be preserved, with no over-shortening of the pre-existing shortened posterior RC.

The treatment choice for type C glenoid remains a matter of debate [49,72]. Clinical results always rely upon the amount of available glenoid bone for fixation after reaming. A baseplate with single, short peg is often required [73]. *Bonneville et al.* [74] considered hemiarthroplasty as a reliable option and demonstrated marked improvement in functional outcome at 2-year follow-up in 9 patients. In the same context, *Edwards et al.* [75] reported significant improvement at a mean of 37 months in 15 patients managed with hemiarthroplasty or TSA. On contrary, glenoid arthrosis was documented in three out of four patients treated with hemiarthroplasty and underwent conversion to TSA after 16 months. *Sperling et al*. [73] reported that hemiarthroplasty might be unsatisfactory for Type C2.

- **Two-stage reconstruction**

This option was proposed after the incline in graft resorption rate and glenoid loosening. Waiting till full graft incorporation should be considered while it is articulating with the implanted humeral prosthesis, then after at least six months with full graft incorporation, the glenoid baseplate can be implanted [76].

This management option is reserved for advanced Seebauer types E3/C3 and E4/C4. A two-stage reconstruction is indicated when tat least 50% of the central peg cannot anchor the native glenoid. A composite graft is implanted into the glenoid defect and fixed with cortical screws for graft stability. Consequently, in occasion of centric defects, a modular humeral component is utilized through a hemiarthroplasty, whilst, in cases with eccentric defects, a resection arthroplasty is done. Graft failure might occur with hemiarthroplasty in eccentric defects [76].

Recent modalities

3D-CT-scans have been recently advantageous for understanding the degree of glenoid deficiency in all directions. Patient specific instrumentation (PSI) and 3D printing techniques have evolved to increase surgeon efficiency and accuracy for a proper glenoid implantation with the desirable version and inclination [77].

Conclusion

Glenoid bone deficiency remains an obstacle that should be precisely managed in the setting of shoulder arthroplasty to obtain a durable stable prosthesis. Different classification systems exist for classifying glenoid wear pattern in different planes. Modifications of these classifications are routinely performed to include the former non-addressed glenoid deficiency pattern. They guide for choosing the proper treatment method. Management methods represent hemiarthroplasty with or without ream-and-run procedure, TSA after asymmetric reaming augmented and custom-made prosthesis, RSA. Grafting is often utilized during either conventional total arthroplasty or reverse arthroplasty.

Acknowledgements:

None

Conflict of interest declaration:

Not applicable

Funding/ financial support:

None

Ethical Clearance

Not required.

References

[1] Edelson J. Localized glenoid hypoplasia. An anatomic variation of possible clinical significance. Clinical orthopaedics and related research. 1995(321): 189-95.DOI. 10.1302/0301-620x.74b4.1624522

[2] Hoenecke HR, Hermida JC, Dembitsky N, Patil S, D'lima DD. Optimizing glenoid component position using three-dimensional computed tomography reconstruction. Journal of shoulder and elbow surgery. 2008;17(4): 637-41.DOI. 10.1016/j.jse.2009.08.009

[3] Shapiro TA, McGarry MH, Gupta R, Lee YS, Lee TQ. Biomechanical effects of glenoid retroversion in total shoulder arthroplasty. Journal of shoulder and elbow surgery. 2007;16(3): S90-S5. DOI. 10.1016/j.jse.2006.07.010

[4] Terrier A, Büchler P, Farron A. Influence of glenohumeral conformity on glenoid stresses after total shoulder arthroplasty. Journal of shoulder and elbow surgery. 2006;15(4):515-20. DOI. 10.1016/j.jse.2005.09.021

[5] Walch G, Badet R, Boulahia A, Khoury A. Morphologic study of the glenoid in primary glenohumeral osteoarthritis. The Journal of arthroplasty. 1999;14(6):756-60. DOI. 10.1016/s0883-5403(99)90232-2

[6] Bercik MJ, Kruse II K, Yalizis M, Gauci M-O, Chaoui J, Walch G. A modification to the Walch classification of the glenoid in primary glenohumeral osteoarthritis using three-dimensional imaging. Journal of shoulder and elbow

surgery. 2016;25(10):1601-6. DOI. 10.1016/j.jse.2016.03.010
[7] Habermeyer P, Magosch P, Luz V, Lichtenberg S. Three-dimensional glenoid deformity in patients with osteoarthritis: a radiographic analysis. JBJS. 2006;88(6):1301-7. DOI. 10.2106/JBJS.E.00622
[8] Sirveaux F, Favard L, Oudet D, Huquet D, Walch G, Mole D. Grammont inverted total shoulder arthroplasty in the treatment of glenohumeral osteoarthritis with massive rupture of the cuff: results of a multicentre study of 80 shoulders. The Journal of bone and joint surgery British volume. 2004;86(3):388-95. DOI. 10.1302/0301-620x.86b3.14024
[9] Huguet D, Favard L, Lautman S, Sirveaux F, Kerjean Y, Oudet D. Epidemiology, imaging, and classification of glenohumeral osteoarthritis with massive and non-reparable rotator cuff tear. Walch G, Boileau P, Mole D, eds. 2000.
[10] Malhas A, Rashid A, Copas D, Bale S, Trail I. Glenoid bone loss in primary and revision shoulder arthroplasty. Shoulder & Elbow. 2016;8(4):229-40. DOI. 10.1177/1758573216648601
[11] Hamada K, Fukuda H, Mikasa M, Kobayashi Y. Roentgenographic findings in massive rotator cuff tears. A long-term observation. Clinical orthopaedics and related research. 1990(254):92-6.
[12] Walch G, Edwards TB, Boulahia A, Nové-Josserand L, Neyton L, Szabo I. Arthroscopic tenotomy of the long head of the biceps in the treatment of rotator cuff tears: clinical and radiographic results of 307 cases. Journal of Shoulder and Elbow Surgery. 2005;14(3):238-46. DOI. 10.1016/j.jse.2004.07.008
[13] Nove-Josserand L, Walch G, Adeleine P, Courpron P. Effect of age on the natural history of the shoulder: a clinical and radiological study in the elderly. Revue de chirurgie orthopedique et reparatrice de l'appareil moteur. 2005;91(6):508-14. DOI. 10.1016/s0035-1040(05)84440-x
[14] Frankle MA, Teramoto A, Luo Z-P, Levy JC, Pupello D. Glenoid morphology in reverse shoulder arthroplasty: classification and surgical implications. Journal of shoulder and elbow surgery. 2009;18(6):874-85. DOI. 10.1016/j.jse.2009.02.013
[15] Antuna SA, Sperling JW, Cofield RH, Rowland CM. Glenoid revision surgery after total shoulder arthroplasty. Journal of shoulder and elbow surgery. 2001;10(3):217-24. DOI. 10.1067/mse.2001.113961
[16] Page RS, Haines JF, Trail I. Impaction bone grafting of the glenoid in revision shoulder arthroplasty: classification, technical description and early results. Shoulder & Elbow. 2009;1(2):81-8. DOI. 10.1111/j.1758-5740.2009. 00017.x
[17] Rockwood Jr C, Matsen III F, Wirth M. Lippitt SB. The shoulder. Philadelphia: Elsevier Health Sciences; 2009.
[18] Hendel MD, Werner BC, Camp CL, Gulotta LV, Walch G, Dines D, et al. Management of the biconcave (B2) glenoid in shoulder arthroplasty: technical considerations. Am J Orthoped. 2016;45(4):220-7.
[19] Matsen FA, Warme WJ, Jackins SE. Can the ream and run procedure improve glenohumeral relationships and function for shoulders with the arthritic triad? Clinical Orthopaedics and Related Research®. 2015;473(6):2088-96. DOI. 10.1007/s11999-014-4095-7
[20] Hsu JE, Ricchetti ET, Huffman GR, Iannotti JP, Glaser DL. Addressing glenoid bone deficiency and asymmetric posterior erosion in shoulder arthroplasty. Journal of Shoulder and Elbow Surgery. 2013;22(9):1298-308. DOI. 10.1016/j.jse.2013.04.014
[21] Parsons IV I, Millett PJ, Warner JJ. Glenoid wear after shoulder hemiarthroplasty: quantitative radiographic analysis. Clinical Orthopaedics and Related Research®. 2004; 421:120-5. DOI. 10.1097/01.blo.0000119249. 61696.f1
[22] Elhassan B, Ozbaydar M, Diller D, Higgins LD, Warner JJ. Soft-tissue resurfacing of the glenoid in the treatment of glenohumeral arthritis in active patients less than fifty years old. JBJS. 2009;91(2):419-24. DOI. 10.2106/JBJS.H.00318
[23] Burkhead Jr W, Hutton KS. Biologic resurfacing of the glenoid with hemiarthroplasty of the shoulder. Journal of Shoulder and Elbow Surgery. 1995;4(4):263-70. DOI.10.1016/S1058-2746(05)80019-9
[24] Clinton J, Franta AK, Lenters TR, Mounce D, Matsen FA. Nonprosthetic glenoid arthroplasty with humeral hemiarthroplasty and total shoulder arthroplasty yield similar self-assessed outcomes in the management of comparable patients with glenohumeral arthritis. Journal of Shoulder and Elbow Surgery. 2007;16(5):534-8. DOI. 10.1016/j.jse.2006.11.003
[25] Levine WN, Djurasovic M, Glasson J-M, Pollock RG, Flatow EL, Bigliani LU. Hemiarthroplasty for glenohumeral osteoarthritis: results correlated to degree of glenoid wear. Journal of Shoulder and Elbow Surgery. 1997;6(5):449-54. DOI. 10.1016/s1058-2746(97)70052-1
[26] Gilmer BB, Comstock BA, Jette JL, Warme WJ, Jackins SE, Matsen III FA. The prognosis for improvement in comfort and function after the ream-and-run arthroplasty for glenohumeral arthritis: an analysis of 176 consecutive cases. JBJS. 2012;94(14):e102. DOI. 10.2106/JBJS.K.0048
[27] Lynch JR, Franta AK, Montgomery Jr WH, Lenters TR, Mounce D, Matsen III FA. Self-assessed outcome at two to four years after shoulder hemiarthroplasty with concentric glenoid reaming. JBJS. 2007;89(6):1284-92. DOI. 10.2106/JBJS.E.00942
[28] Donohue KW, Ricchetti ET, Iannotti JP. Surgical management of the biconcave (B2) glenoid. Current reviews in musculoskeletal medicine. 2016;9(1):30-9. DOI. 10.1007/s12178-016-9315-1
[29] Clavert P, Millett PJ, Warner JJ. Glenoid resurfacing: what are the limits to asymmetric reaming for posterior erosion? Journal of shoulder and elbow surgery. 2007;16(6):843-8. DOI. 10.1016/j.jse.2007.03.015
[30] Gillespie R, Lyons R, Lazarus M. Eccentric reaming in total shoulder arthroplasty: a cadaveric study. Orthopedics (Online). 2009;32(1):21. DOI. 10.3928/01477447-20090101-07
[31] Neer 2nd C, Morrison D. Glenoid bone-grafting in total shoulder arthroplasty. JBJS. 1988;70(8):1154-62.
[32] Smith MJ, Loftis CM, Skelley NW. Eccentric reaming for B2 glenoids: history, preoperative planning, surgical technique, and outcome. Journal of Shoulder and Elbow Arthroplasty. 2019;3:??? DOI. 10.1177/2471549219870348
[33] Walch G, Young AA, Boileau P, Loew M, Gazielly D, Molé D. Patterns of loosening of polyethylene keeled glenoid components after shoulder arthroplasty for primary osteoarthritis: results of a multicenter study with more than five years of follow-up. JBJS. 2012;94(2):145-50. DOI. 10.2106/JBJS.J.00699
[34] Orvets ND, Chamberlain AM, Patterson BM, Chalmers PN, Gosselin M, Salazar D, et al. Total shoulder arthroplasty in patients with a B2 glenoid addressed with corrective reaming. Journal of shoulder and elbow

surgery. 2018;27(6): S58-S64. DOI. 10.1016/j.jse.2018.01.003

[35] Gerber C, Costouros JG, Sukthankar A, Fucentese SF. Static posterior humeral head subluxation and total shoulder arthroplasty. Journal of Shoulder and Elbow Surgery. 2009;18(4):505-10. DOI. 0.1016/j.jse.2009.03.003

[36] Habermeyer P, Magosch P, Lichtenberg S. Recentering the Humeral Head for Glenoid Deficiency in Total Shoulder Arthroplasty. Clinical Orthopaedics and Related Research®. 2007;457. DOI. 10.1097/BLO.0b013e31802ff03c

[37] Strauss EJ, Roche C, Flurin P-H, Wright T, Zuckerman JD. The glenoid in shoulder arthroplasty. Journal of shoulder and elbow surgery. 2009;18(5):819-33. DOI. 10.1016/j.jse.2009.05.008

[38] Klika BJ, Wooten CW, Sperling JW, Steinmann SP, Schleck CD, Harmsen WS, et al. Structural bone grafting for glenoid deficiency in primary total shoulder arthroplasty. Journal of shoulder and elbow surgery. 2014;23(7):1066-72. DOI. 10.1016/j.jse.2013.09.017

[39] Hill JM, Norris TR. Long-term results of total shoulder arthroplasty following bone-grafting of the glenoid. JBJS. 2001;83(6):877-83.

[40] Bateman E, Donald SM. Reconstruction of massive uncontained glenoid defects using a combined autograft-allograft construct with reverse shoulder arthroplasty: preliminary results. Journal of Shoulder and Elbow Surgery. 2012;21(7):925-34. DOI. 10.1016/j.jse.2011.07.009

[41] Steinmann SP, Cofield RH. Bone grafting for glenoid deficiency in total shoulder replacement. Journal of shoulder and elbow surgery. 2000;9(5):361-7. DOI. 10.1067/mse.2000.106921

[42] Sabesan V, Callanan M, Ho J, Iannotti JP. Clinical and radiographic outcomes of total shoulder arthroplasty with bone graft for osteoarthritis with severe glenoid bone loss. JBJS. 2013;95(14):1290-6. DOI.

[43] Walch G, Moraga C, Young A, Castellanos-Rosas J. Results of anatomic nonconstrained prosthesis in primary osteoarthritis with biconcave glenoid. Journal of Shoulder and Elbow Surgery. 2012;21(11):1526-33. DOI. 10.2106/JBJS.L.00097

[44] Nowak DD, Bahu MJ, Gardner TR, Dyrszka MD, Levine WN, Bigliani LU, et al. Simulation of surgical glenoid resurfacing using three-dimensional computed tomography of the arthritic glenohumeral joint: the amount of glenoid retroversion that can be corrected. Journal of shoulder and elbow surgery. 2009;18(5):680-8. DOI. 10.1016/j.jse.2009.03.019

[45] Sabesan V, Callanan M, Sharma V, Iannotti JP. Correction of acquired glenoid bone loss in osteoarthritis with a standard versus an augmented glenoid component. Journal of shoulder and elbow surgery. 2014;23(7):964-73. DOI. 10.1016/j.jse.2013.09.019

[46] Cil A, Sperling JW, Cofield RH. Nonstandard glenoid components for bone deficiencies in shoulder arthroplasty. Journal of shoulder and elbow surgery. 2014;23(7):e149-e57. DOI. 10.1016/j.jse.2013.09.023

[47] Iannotti JP, Lappin KE, Klotz CL, Reber EW, Swope SW. Liftoff resistance of augmented glenoid components during cyclic fatigue loading in the posterior-superior direction. Journal of shoulder and elbow surgery. 2013;22(11):1530-6. DOI. 10.1016/j.jse.2013.01.018

[48] Rice RS, Sperling JW, Miletti J, Schleck C, Cofield RH. Augmented glenoid component for bone deficiency in shoulder arthroplasty. Clinical orthopaedics and related research. 2008;466(3):579-83. DOI. 10.1007/s11999-007-0104

[49] Gunther SB, Lynch TL. Total shoulder replacement surgery with custom glenoid implants for severe bone deficiency. Journal of Shoulder and Elbow Surgery. 2012;21(5):675-84. DOI. 10.1016/j.jse.2011.03.023

[50] Sandow M, Schutz C. Total shoulder arthroplasty using trabecular metal augments to address glenoid retroversion: the preliminary result of 10 patients with minimum 2-year follow-up. Journal of shoulder and elbow surgery. 2016;25(4):598-607. DOI. 10.1016/j.jse.2016.01.00

[51] Gilot GJ. Addressing glenoid erosion in reverse total shoulder arthroplasty. Bulletin of the NYU Hospital for Joint Diseases. 2013;71(2):S51.

[52] Mizuno N, Denard PJ, Raiss P, Walch G. Reverse total shoulder arthroplasty for primary glenohumeral osteoarthritis in patients with a biconcave glenoid. JBJS. 2013;95(14):1297-304. DOI. 10.2106/JBJS.L.00820

[53] Gerber C, Pennington SD, Nyffeler RW. Reverse total shoulder arthroplasty. JAAOS-Journal of the American Academy of Orthopaedic Surgeons. 2009;17(5):284-95. DOI. 10.5435/00124635-200905000-00003

[54] Klein SM, Dunning P, Mulieri P, Pupello D, Downes K, Frankle MA. Effects of acquired glenoid bone defects on surgical technique and clinical outcomes in reverse shoulder arthroplasty. JBJS. 2010;92(5):1144-54. DOI. 10.2106/JBJS.I.00778

[55] Neyton L, Boileau P, Nové-Josserand L, Edwards TB, Walch G. Glenoid bone grafting with a reverse design prosthesis. Journal of Shoulder and Elbow Surgery. 2007;16(3):S71-S8. DOI. 10.1016/j.jse.2006.02.002

[56] Norris TR, Kelly JD, Humphrey CS. Management of glenoid bone defects in revision shoulder arthroplasty: a new application of the reverse total shoulder prosthesis. Techniques in Shoulder & Elbow Surgery. 2007;8(1):37-46. DOI. 10.1097/BTE.0b013e318030d3b7

[57] Werner BS, Böhm D, Abdelkawi A, Gohlke F. Glenoid bone grafting in reverse shoulder arthroplasty for long-standing anterior shoulder dislocation. Journal of Shoulder and Elbow Surgery. 2014;23(11):1655-61. DOI. 10.1016/j.jse.2014.02.017

[58] Boileau P, Watkinson DJ, Hatzidakis AM, Balg F. Grammont reverse prosthesis: design, rationale, and biomechanics. Journal of shoulder and elbow surgery. 2005;14(1):S147-S61. DOI. 10.1016/j.jse.2004.10.006

[59] Lopiz Y, García-Fernández C, Arriaza A, Rizo B, Marcelo H, Marco F. Midterm outcomes of bone grafting in glenoid defects treated with reverse shoulder arthroplasty. Journal of Shoulder and Elbow Surgery. 2017;26(9):1581-8. DOI. 10.1016/j.jse.2017.01.017

[60] Jones RB, Wright TW, Zuckerman JD. Reverse total shoulder arthroplasty with structural bone grafting of large glenoid defects. Journal of Shoulder and Elbow Surgery. 2016;25(9):1425-32. DOI. 10.1016/j.jse.2016.01.016

[61] Boileau P, Moineau G, Roussanne Y, O'Shea K. Bony increased-offset reversed shoulder arthroplasty: minimizing scapular impingement while maximizing glenoid fixation. Clinical Orthopaedics and Related Research®. 2011;469(9):2558-67. DOI. 10.1007/s11999-011-1775-4

[62] Bogle A, Budge M, Richman A, Miller RJ, Wiater JM, Voloshin I. Radiographic results of fully uncemented trabecular metal reverse shoulder system at 1 and 2 years' follow-up. Journal of Shoulder and Elbow Surgery. 2013;22(4):e20-e5. DOI. 10.1016/j.jse.2012.08.019

[63] Holcomb JO, Cuff D, Petersen SA, Pupello DR, Frankle MA. Revision reverse shoulder arthroplasty for glenoid

baseplate failure after primary reverse shoulder arthroplasty. Journal of shoulder and elbow surgery. 2009;18(5):717-23. DOI. 10.1016/j.jse.2008.11.017

[64] Macaulay AA, Greiwe RM, Levine WN. Reverse total shoulder replacement in patients with severe glenoid bone loss. Operative Techniques in Orthopaedics. 2011;21(1):86-93.

[65] Elhassan B, Ozbaydar M, Higgins LD, Warner JJ. Glenoid reconstruction in revision shoulder arthroplasty. Clinical orthopaedics and related research. 2008;466(3):599-607. DOI. 10.1007/s11999-007-0108-0

[66] Walker M, Willis MP, Brooks JP, Pupello D, Mulieri PJ, Frankle MA. The use of the reverse shoulder arthroplasty for treatment of failed total shoulder arthroplasty. Journal of Shoulder and Elbow Surgery. 2012;21(4):514-22. DOI. 10.1016/j.jse.2011.03.006

[67] Kelly JD, Zhao JX, Hobgood ER, Norris TR. Clinical results of revision shoulder arthroplasty using the reverse prosthesis. Journal of Shoulder and Elbow Surgery. 2012;21(11):1516-25. DOI. 10.1016/j.jse.2011.11.021

[68] Walch G, Bacle G, Lädermann A, Nové-Josserand L, Smithers CJ. Do the indications, results, and complications of reverse shoulder arthroplasty change with surgeon's experience? Journal of shoulder and elbow surgery. 2012;21(11):1470-7. DOI. 10.1016/j.jse.2011.11.010.

[69] Melis B, Bonnevialle N, Neyton L, Lévigne C, Favard L, Walch G, et al. Glenoid loosening and failure in anatomical total shoulder arthroplasty: is revision with a reverse shoulder arthroplasty a reliable option? Journal of Shoulder and Elbow Surgery. 2012;21(3):342-9. DOI. 10.1016/j.jse.2011.05.021

[70] Khoury A, Walch G, Badet R, Boulaiha A. Morphologic study of the Glenoid in primary glenohumeral osteoarthritis. 1999. DOI. 10.1016/s0883-5403(99)90232-2

[71] Mori D, Abboud JA, Namdari S, Williams GR. Glenoid bone loss in anatomic shoulder arthroplasty: literature review and surgical technique. Orthopedic Clinics. 2015;46(3):389-97. DOI. 10.1016/j.ocl.2015.02.007

[72] Denard PJ, Walch G. Current concepts in the surgical management of primary glenohumeral arthritis with a biconcave glenoid. Journal of Shoulder and Elbow Surgery. 2013;22(11):1589-98. DOI.

[73] Sperling JW, Cofield RH, Steinmann SP. Shoulder Arthroplasty for Osteoarthritis Secondary to Glenoid Dysplasia. JBJS. 2002;84(4). DOI. 10.1016/j.jse.2013.06.017

[74] Bonnevialle N, Mansat P, Mansat M, Bonnevialle P. Hemiarthroplasty for osteoarthritis in shoulder with dysplastic morphology. Journal of Shoulder and Elbow Surgery. 2011;20(3):378-84. DOI. 10.1016/j.jse.2010.07.006

[75] Edwards TB, Boulahia A, Kempf J-F, Boileau P, Némoz C, Walch G. Shoulder arthroplasty in patients with osteoarthritis and dysplastic glenoid morphology. Journal of Shoulder and Elbow Surgery. 2004;13(1):1-4. DOI. 10.1016/j.jse.2003.09.011

[76] Gupta A, Thussbas C, Koch M, Seebauer L. Management of glenoid bone defects with reverse shoulder arthroplasty—surgical technique and clinical outcomes. Journal of Shoulder and Elbow Surgery. 2018;27(5):853-62. DOI. 10.1016/j.jse.2017.10.004

[77] Sprowls GR, Wilson CD, Stewart W, Hammonds KA, Baruch NH, Ward RA, et al. Intraoperative navigation and preoperative templating software are associated with increased glenoid baseplate screw length and use of augmented baseplates in reverse total shoulder arthroplasty. 2021;5(1):102-8. DOI. 10.1016/j.jseint.2020.09.003