Acta Biomed 2023; Vol. 94, Supplement 2: e2023120 DOI: 10.23750/abm.v94iS2.14042

Original article

The use of a large diameter glenosphere in reverse shoulder arthroplasty for proximal humeral fractures in elderly patients undergoing tuberosity removal

Rendina Michele[1], Mahagna Antonio Abed[2], Roveda Giacomo[3], Torriani Camilla[4], Pelliccia Giovanni[5], Grassi Federico Alberto[6]

[1]Department of Orthopedics and Traumatology, IRCCS Policlinico San Matteo, Pavia, Italy; [2]Department of Orthopedics and Traumatology, IRCCS Policlinico San Matteo, University of Pavia, Pavia, Italy; [3]University of Pavia, Pavia, Italy; [4]University of Pavia, Pavia, Italy; [5]Department of Orthopedics and Traumatology, IRCCS Policlinico San Matteo, University of Pavia, Pavia, Italy; [6]Department of Orthopedics and Traumatology, IRCSS Policlinico San Matteo, University of Pavia, Pavia, Italy

Abstract. *Background and aim:* Prosthetic replacement with reverse shoulder arthroplasty (RSA) is commonly indicated for complex proximal humerus fractures (PHFs) in elderly patients. Aim of this study was to evaluate the clinical and radiological outcomes of RSA performed for comminuted PHFs, without periprosthetic reconstruction of the tuberosities. Our hypothesis was that a large diameter glenosphere could ensure satisfactory RSA mobility and stability, regardless of tuberosity removal. *Methods:* We selected 32 patients (4 men, 28 women) with comminuted PHFs who underwent RSA with tuberosity excision and implantation of a 44-mm glenosphere between 2009 and 2015. Active range of motion (ROM), stability, Constant-Murley Score (CMS) (1) and Subjective Shoulder Value (SSV) (2) were assessed one year and four years after surgery. *Results:* Clinical and radiological information were collected for 23 patients (72%). At one-year follow-up, active anterior elevation (AE) was 96±28 degrees, external rotation with adducted arm (ER1) 9±7 degrees, external rotation with abducted arm (ER2) 14±10 degrees, internal rotation (IR) to L4; CMS was 56±10 and SSV 65±22. Clinical assessment at 4-year follow up showed a decrease in active ROM (AE was 88±20 degrees, ER1 8±2 degrees, ER2 12±10 degrees, IR to L4), CMS (52±9) and SSV (62±8). No RSA dislocation occurred during the study. In 4 patients, grade I glenoid notching without any sign of component loosening was observed 4 years after surgery. *Conclusions:* A large diameter glenosphere does not ensure results comparable to those achieved after RSA with tuberosity reconstruction. However, the 44-mm glenosphere was effective in preventing RSA instability. (www.actabiomedica.it)

Key words: geriatric surgery, shoulder surgery, tuberosity removal, large diameter glenosphere, reverse shoulder arthroplasty, treatment of proximal humeral fractures

Introduction

Surgical treatment of comminuted PHFs in elderly patients is still a controversial topic. Comminution of the tuberosities is often accompanied by poor bone quality and massive rotator cuff tears, making reconstruction difficult and consolidation uncertain.

In these cases, the advantages offered by prosthetic replacement with RSA are well documented. In fact, joint function is influenced only partially by the rotator cuff, the surgical technique is simpler than anatomical replacement, the rehabilitation program is accelerated and simplified (3).

Several authors have investigated the issues associated with tuberosity reconstruction in RSA for PHFs and how tuberosity healing can influence the clinical outcome (4, 5).

If removal of the tuberosities is performed or tuberosity healing doesn't occur, internal and external rotation movements should be partially compensated by the action of the shoulder adductors and posterior deltoid, with variable limitations in active ROM (4, 5). Moreover, the stabilizing force exerted by the rotator cuff is lost, increasing the risk of RSA dislocation and instability (6, 7, 8).

The purpose of this study is to evaluate the clinical and functional results achieved after implantation of RSA, using a large diameter glenosphere (44 mm) and not performing tuberosity reconstruction, in a series of elderly patients affected by comminuted PHFs.

Our hypothesis is that a large diameter glenosphere might ensure satisfactory shoulder mobility and stability in case of RSA with removal of the tuberosities.

Patients and methods

Between February 2009 and November 2015, 91 patients older than 70 years underwent RSA following acute plurifragmentary PHFs at a single institution. In 32 cases (35.1%) the tuberosities were removed during surgery, due to their comminution: these patients were included in the study. Patients affected by pathological fractures and those with significant cognitive impairment were excluded from this series.

28 patients were females (87.5%) with a mean age of 82 years (range, 71-84), while 4 were males (12.5%) with a mean age of 75 years (range, 70-81). Overall, the mean age was of 79.4 years (range 70-84). In 23 patients (71,8%), the fractured limb was the dominant one.

The mechanism of injury was a fall from standing height in 27 cases, a traffic accident in three cases and a fall from a bicycle in two cases.

The average interval from injury to surgery was three days (range 2-7 days). A preoperative CT scan was performed in all patients in order to better define the fracture pattern.

Most of the patients suffered from comorbidities: 17 were affected by hypertension, 7 by cardiovascular diseases, 4 by diabetes, 4 by morbid obesity, 2 by thyroid disease, 1 by obstructive lung disease and 1 by renal disease.

Surgical technique and postoperative rehabilitation

Patients were put under general anesthesia, combined with interscalene brachial plexus block, and placed in the beach-chair position. Preoperative antibiotics (Cephazolin 2g iv) were administered at the induction of anesthesia. The operations were performed through a delto-pectoral approach by a single surgeon (M.R.). The tuberosity fragments were resected before implanting the prosthesis. In all patients, a 44-mm polyethylene glenosphere was implanted and fixed with two 6.5 mm cancellous bone screws (SMR prosthesis, Lima Corporate, San Daniele del Friuli, Italy). All the humeral stems were uncemented. Retroversion, stem diameter and liner height were chosen intraoperatively by the surgeon with empirical assessment of implant stability and soft tissue tension. A suction drain was placed in the surgical wound before skin closure. X-rays of the operated shoulder were taken in the recovery room immediately after surgery and the arm was protected in a sling.

Active assisted mobilization in forward elevation was started on the first postoperative day, when the surgical drain was removed. After two weeks, the patients were encouraged to move actively the operated shoulder by themselves without undue efforts. Between 30 and 45 days after surgery, patients were allowed to return to normal activities of daily living.

The average time from surgery to discharge was two days (range, 1-3 days)

Clinical and radiographic examinations were scheduled at 3, 6 and 12 months after surgery, then once a year.

At follow up, active ROM was measured with a goniometer (9, 10) in anterior elevation (AE), external rotation with adducted arm (ER1) and external rotation at 90° of abduction (ER2), while internal rotation (IR) was determined by the highest vertebral level reached by the patient's thumb, then converted to numerical values (Table 1).

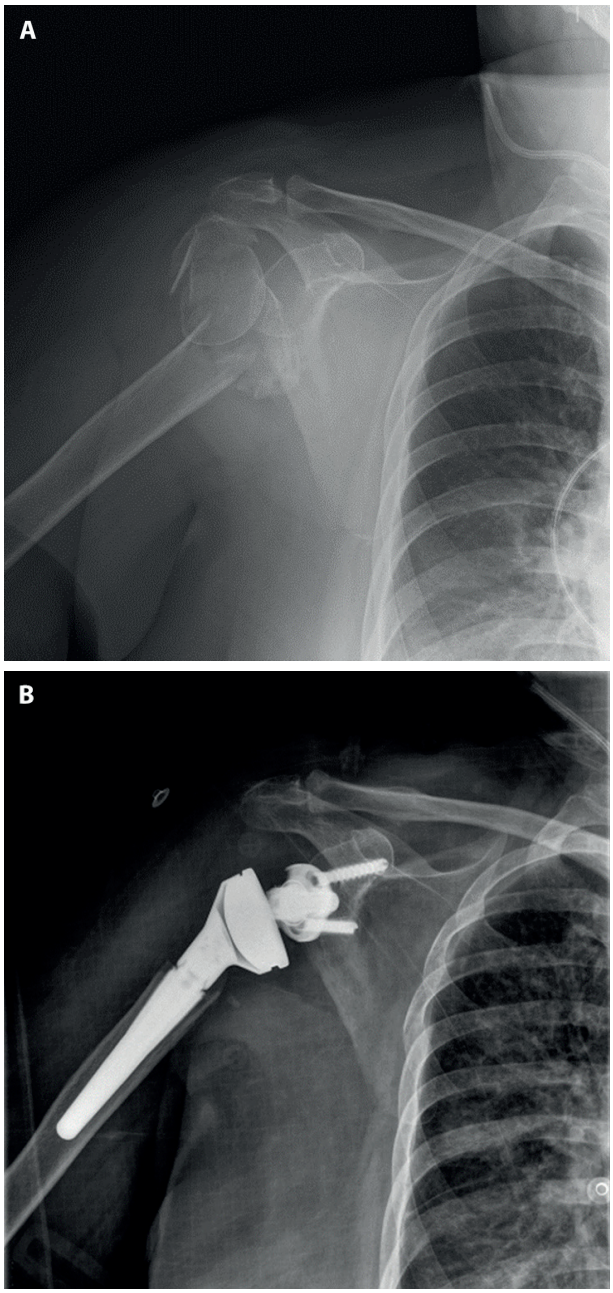

Figure 1. (a) Plurifragmentary PHF in a 70 year old woman, affected by concomitant massive rotator cuff tear. (b) Postoperative X-rays after RSA (44-mm polyethylene glenosphere) with resection of the tuberosity fragments.

The absolute, relative and normalized CMS and the Subjective Shoulder Value (SSV) were recorded 1 year and 4 years postoperatively (1, 2).

X-rays of the shoulder were taken in two views (A-P and true A-P on the scapular plane), paying special attention to glenoid notching and implant osseointegration (Figure 1).

Table 1. Internal rotation numeric scale.

Level reached	Points
lateral thigh	0
buttocks	2
lumbosacral junction	4
waist (L3)	6
T12	8
Interscapular (T7)	10

We also compared the length of the operated arm with the contralateral. Two operators performed three length measurements of both upper limbs and obtained intraobserver and interobserver estimates (10). The bony landmarks for measurement were the posterolateral angle of the acromion proximally and the apex of the olecranon distally, with the elbow flexed at 90°.

Statistical analysis was performed using the Student's t-test for comparing ROM, CMS and SSV at 1 and 4 years after surgery. Statistical significance was set at $P < 0.05$.

Results

At the 4-year follow up, 23 patients (21 women, 2 men) were available for evaluation. The dropout rate was 28% (9 patients): 3 patients died during the follow up period, 4 were untraceable and 2 were unable to attend the outpatient visit.

The mean age of the evaluated patients at the time of operation was 76.2 (range 74-88).

Only 10 patients (43,4%) had undergone a supervised rehabilitation program. More than half of the patients performed functional re-education independently or with the help of family members.

Postoperative complications included 6 cases of arm paresthesia, that resolved uneventfully within 4 months. No other early or late complications were observed, in particular RSA dislocations.

Active ROM recorded at 1 year and 4 years after surgery are reported in Table 2.

Table 2. Active ROM at 1 year and 4 years after surgery (values are means and standard deviations).

	1 year follow-up	4 year follow-up		*P* value	*P* value
		Operated shoulder	*Contralateral shoulder*	*1 vs 4 year follow-up*	*operated vs contralateral arm*
AE	96 ± 28	88 ± 20	144 ± 30	0.309	***0.0001***
ER1	9 ± 7	8 ± 2	46 ± 4	0.256	***0.0001***
ER2	14 ±10	12 ± 10	60 ± 15	0.514	***0.0001***
IR	6.52 ± 2.78	5.56 ± 3.06	8.17 ± 1.43	0.299	***0.0001***

Legend*:* AE= anterior elevation, ER1= external rotation with arm adducted, ER2= external rotation at 90° abduction, IR= internal rotation (vertebral level converted to numerical value).

Table 3. Constant-Murley Score and Subjective Shoulder Value recorded at one year and four years after surgery.

Constant-Murley Score	**1 year**	**4 years**	***P* value**
Absolute (100 points)	**56** ± 10	**52** ± 9	*0.171*
Pain (15 points)	*8 ± 3*	*8 ± 5*	*0.595*
Activity level (20 points)	*14 ± 3*	*12 ± 6*	*0.091*
Range of motion (40 points)	*24 ± 5*	*21 ± 4*	***0.016***
Strength (25 points)	*10 ± 5*	*11 ± 6*	*0.519*
Normalized CMS (%)	**82** ± 19	**72** ± 21	***0.0001***
Relative CMS (%)	**72** ± 8	**67** ± 12	***0.0001***
Subjective Shoulder Value (%)	**65** ± 22	**62** ± 8	***0.522***

The Constant-Murley Score (CMS) and Subjective Shoulder Value Score (SSV) scores of the 23 evaluated patients are shown in Table 3.

The average arm elongation, compared to the contralateral limb, was 19.4 mm (range, 15-29 mm).

Radiographic examination at 1 year didn't show any scapular notching in the operated shoulders, while at 4 years there were evidence of Sirveaux grade 1 notching in 4 patients (11). No radiographic signs of implant loosening or scapular stress fractures were detected at follow up.

Discussion

In the elderly population, PHFs are often complicated by fragmentation and displacement of the tuberosities, poor bone quality with decreased potential for consolidation and massive rotator cuff lesions (12). Moreover, postoperative recovery might be hindered by poor compliance to the rehabilitation program.

In these patients, osteosynthesis with anatomical and stable fixation of the fracture fragments is problematic and at risk of complications related to the unpredictable consolidation.

During the last two decades, RSA has progressively gained consensus for the treatment of complex PHFs in elderly patients, with satisfactory results reported by different authors (12, 13, 14). Unlike hemiarthroplasty, in which correct positioning and consolidation of the tuberosities is essential for good results (15, 16, 17, 18), RSA outcomes seem less dependent on tuberosity healing (19).

The influence of tuberosities on ROM and stability of RSA has been extensively investigated in literature. Most authors agree that reconstruction and consolidation of the tuberosities are related to better results. Successful outcomes between 37% and 84% of patients have been reported by different authors after tuberosity healing (5, 20, 21, 22).

In 2013, Gallinet et al. evaluated the outcomes achieved in a series of 41 patients, treated with RSA for complex PHFs (23). Better results (ROM, CMS, DASH) were observed in 18 patients with anatomic tuberosity healing in comparison to the remaining 23 patients, in whom the tuberosities were not surgically repaired or progressed to non-union or malunion.

Ohl et al. (8) reported the results observed in a multicentric study on 420 patients, who were divided in three groups according to the status of the greater tuberosity (GT) after RSA for PHFs: anatomical healing, failed fixation and excision. Functional results were significantly better among patients with GT healing, while the instability rate was higher in patients who had undergone GT removal during surgery.

In a recent retrospective study, Schmalzl et al. (5) reported the results achieved in 38 patients treated for PHFs, using RSA with 135° humeral inclination and a standard medialized glenosphere. A high rate (82%) of GT healing was observed and was associated with significantly better outcomes. The authors hypothesized that a more anatomic design of the prosthesis might contribute to tuberosity healing owing to the decreased stresses acting on the repair.

Even though most of authors recommend tuberosity reconstruction to achieve better outcomes after RSA for PHFs, there are some studies that did not highlight significant differences in clinical results between patients with or without tuberosity consolidation (21, 22, 24).

In this study we reported our experience in a series of elderly patients, in whom tuberosity reconstruction was not performed. We took this decision when fragment comminution, poor bone quality and massive cuff tears were present. In the attempt to maximize ROM and stability, we decided to implant a large diameter glenosphere. This solution should improve the rotational action of the deltoid 6 at the cost of increasing the force required to raise the arm on the scapular plane (25, 26).

Other potential drawbacks must be considered when implanting a large diameter glenosphere. These include the higher risk of acromial stress fractures, with a decreased efficiency in muscle function (25, 27), and the increased stresses at the baseplate bone-implant interface, that might interfere with bone integration (28) and lead to prosthesis loosening (25).

Some experimental studies have been carried out to investigate the biomechanical behavior of large diameter glenosphere. A laboratory model by Chou et al. (29) showed that 44 mm glenospheres, compared to 36 mm, improve the minimum abduction angle by 11.6° and the maximum abduction angle by 11.1°, increasing the overall range of motion in abduction by 22.7°. Gutierrez et al. (30), on a computer model, found that lateralization of the center of rotation and large diameter glenospheres are able to increase impingement-free ROM and decrease adduction deficit of RSA, with potential positive repercussions on stability and scapular notching. Similar results were reported by Virani et al. (31) in a three-dimensional virtual shoulder model, comparing three different glenosphere diameters (30, 36 and 42 mm) in different RSA component combinations.

From a cadaver study, in which only the teres minor was preserved, Berhouet et al. (32) found that by increasing the glenosphere diameter from 36 to 42 mm, ROM in the scapular plane improved by a total of 14° (4° in abduction and 10° in adduction). However, they underlined that the use of a large diameter glenosphere might be difficult in practice for patients of small stature.

Different authors reported favorable clinical results with the use of large diameter (42 and 44 mm) glenospheres in RSA implanted for non-traumatic pathologies of the shoulder, mainly cuff tear arthropathy (33-35).

The choice of using a 44 mm glenosphere in our series of elderly patients with PHFs was influenced by local anatomic conditions. Excision of the tuberosities improved glenoid exposure and allowed precise implantation of the prosthetic component even in small patients. Our intentions were to ensure immediate postoperative joint stability in order to start an aggressive rehabilitation program as soon as possible.

Active ROM recorded at 1 and 4 years after surgery was not satisfactory. In fact, active movements of the operated shoulders were significantly limited when compared to the contralateral arm, particularly in external rotation. However, loss of active ROM was well tolerated by most of our patients, who were able to perform normal daily activities.

It is difficult to compare our results with those reported in other studies dealing with RSA for PHFs. We focused our attention on the glenosphere diameter, but this parameter was not highlighted in the clinical series reported by other authors. A common denominator with other experiences can be found in the absence or loss of tuberosities.

Ohl et al. (8) used a 36 mm glenosphere in 66% of 120 treated patients, but they did not specify the diameters of the glenospheres implanted in the remaining shoulders. Therefore, it isn't possible to extrapolate the role played by the glenosphere diameter in the patients who underwent excision of the tuberosities. These patients had an average active anterior elevation superior to what recorded in our patients, while comparison of

shoulder rotations and functional scores between the two studies shows inconsistent findings (Table 4). It is noteworthy that these values present a wide variability, as normally happens in clinical series of shoulder arthroplasty for PHFs.

Further comparisons of our results were made with three previous studies, in which the original Delta III prosthesis was used. In comparison to recent clinical series, higher rates of complications were observed in these early experiences of RSA for PHFs.

Klein et al. (19) reported on a series of 20 patients, who underwent RSA for PHFs with excision of the tuberosities. Their outcomes are superior to other similar series in terms of active ROM and absolute CMS (Table 4), but these "optimistic" findings could be related to discrepancies in the methodology adopted for assessing the results.

In 2010, Cazeneuve and Cristofari (36) updated their clinical series of RSA for PHFs and reported the clinical outcomes using exclusively the CMS. Rotations were restricted, while active elevation was satisfactory (Table 4). These authors noticed a reduction in functional outcome at longer follow up, expressing particular concern for the progression of scapular notching. They suggested to remove the tuberosities and avoid anteversion of the humeral component in order to decrease the risk of dislocation.

Gallinet et al. (23) highlighted the difference in clinical outcomes between patients with and without tuberosity repair. Lack of tuberosities yielded functional results that are similar to those reported in the current study, with active shoulder elevation slightly superior and rotations inferior to our findings (Table 4).

In the absence of the rotator cuff, shoulder rotations might be partially compensated by the deltoid action. The deltoid acts primarily as an abductor, but secondarily it could act as an external rotation through its posterior fibers and internal rotator through its anterior fibers (37). However, most of the authors now recommend preserving at least the GT, because external rotation can be provided only by the posterior cuff (8, 20). According to our experience, an increase in glenosphere diameter does not correlate to a parallel increase in active rotational movements, that remain limited, and does not provide any biomechanical advantage in this regard.

Anterior elevation in RSA relies on the action of the deltoid. The prosthesis alters the shape and lever arm of the muscle, according to the geometry of its components. Several experimental models demonstrated that larger glenospheres provide greater abduction ROM, increase joint stability and prevent scapular notching (29, 30, 31, 32, 33, 34, 35, 38, 39). However, the increase in the glenosphere diameter is accompanied by a slight increase in cup thickness and lateralization of the center of rotation (39), that can be negligible if the cup size is chosen according to patient size. In small patients, the changes in spatial

Table 4. Comparison of active ROM and clinical scores (CMS, SSV) in RSA with excision of the tuberosities.

	Present study	**Ohl** *et al.* [29]	**Klein** *et al.* [20]	**Cazeneuve** *et al.* [6]	**Gallinet** *et al.* [11]
n=	23	120	20	36	14
F/U (months)	48	28	33	79	24
AE	88± 20	100.6 ± 24.9	122.67 ± 32.84	7.5 (CMS) ≈ *112°*	95.7
ER1	8 ± 2	6.6 ± 6.6	25 ± 10 †	1 (CMS)	0
ER2	12 ± 10	17.5 ± 5.9			3.6
IR	5.56 ± 3.06	4.0 ± 2.3	L4 (=6)	1 (CMS)	sacrum (=1)
CMS	*absolute* 52 ± 9	*absolute* 53.2 ± 15.2	*absolute* 67.8 ± 13.6	*absolute* 53 *normalized* 69.3	*absolute* 51.7
	normalized 67 ± 12	*normalized* 80.1 ± 23.6			
SSV	62 ± 8	56.5 ± 18.3	-		-

Legend: † arm position not specified

relationships between scapula and humerus might cause an increase in deltoid load, that can have negative effects on active abduction and can contribute to a reduction in shoulder function over time. The latter hypothesis finds confirmation in our series of patients, whose shoulder function worsened during the follow up period.

Removal of the tuberosities relieves the deltoid from the opposing action of the subscapularis and external rotators (40), thus the abduction action of the deltoid should be favored, at least in the first degrees of movement. This facilitation becomes particularly important in the elderly, with reduced muscle performance since it allows them to start the rehabilitation program early and without further obstacles. Unfortunately, we could not perceive a favorable effect on deltoid function with excision of the tuberosities.

In this series of RSA, no complications were observed. RSA causes an elongation of the arm that is necessary to achieve adequate deltoid tension, that is the key factor for adequate postoperative shoulder function and implant stability. Elongation should not exceed 2 cm in order to avoid the risk of neurological injuries and acromial fatigue fractures (41). Taking as a reference the contralateral limb, we measured a mean arm elongation of 19.4 mm (range, 15.6 to 28.1 mm): these values reflect the intraoperative empirical search for the optimal deltoid tension in each individual case.

Despite the lack of the stabilizing effect exerted by the rotator cuff tendons and the limited compliance of patients to postoperative rehabilitation, we did not observe any dislocation, in contrast with findings by other authors (5, 8, 19, 23, 36), who reported a higher rate of RSA dislocations with tuberosity removal. Therefore, we hypothesize that a large diameter glenosphere might increase the stability of RSA when the tuberosities are excised.

An additional positive effect of the 44 mm glenosphere was the prevention of scapular notching. This problem has been addressed and mostly overcome by adopting different prosthetic design and improving the surgical technique. Even though the incidence of notching could be underestimated in this study by the lack of the axillary radiographic view at follow up, the prevalence and severity of notching was extremely low.

This study has important limitations that should be highlighted. It is a single-center study on a limited number of patients, without well-defined inclusion criteria beyond those established by the surgeon intraoperatively. The large diameter glenosphere was not compared to other implants as control, but this is due to the fact that tuberosity removal was performed exclusively when this glenosphere was used.

Conclusions

Our findings support current recommendations to reconstruct the tuberosities, or at least the GT, in RSA for PHFs, even in elderly patients. Excision of the tuberosities negatively affects recovery of active shoulder ROM and impair the functional results obtainable with this procedure.

The use of a large diameter glenosphere cannot compensate for the absence of the rotator cuff tendons, particularly for the recovery of shoulder rotations. Glenosphere dimension should be chosen according to the size of the patient, in order to achieve the best glenohumeral spatial relationship and joint function.

However, in case of severe anatomical impairment with great difficulty in tuberosity reconstruction, a large diameter glenosphere might be useful to decrease the risk of RSA dislocation in the postoperative period, especially in elderly patients with a low compliance for the rehabilitation program.

Conflict of Interest: Each author declares that he or she has no commercial associations (e.g. consultancies, stock ownership, equity interest, patent/licensing arrangement etc.) that might pose a conflict of interest in connection with the submitted article

Ethical Disclosure: The submitted paper has not already been published or submitted for publication elsewhere. It is original and not contains parts taken from other publications. All submissions are accepted with the understanding that they have not been, and will not be, published elsewhere substantially in any format. Also, there should be no ethical concerns with the content or data collection

Authors Contributions Statements: M.R. contributed to the article through conceptualization, methodology and original draft preparation. AA.M. contributed to the article through investigation,

data curation, and editing. G.R. contributed to the article through formal analysis, review and editing. C.T. contributed to the article through data curation and review. G.P. contributed to the article through investigation, data curation and editing. FA.G. contributed to the article through methodology, data curation and review.

References

1. Constant CR, Murley AH. A clinical method of functional assessment of the shoulder. Clin Orthop Relat Res 1987; 160–4.
2. Gilbart MK, Gerber C. Comparison of the subjective shoulder value and the Constant score. J Shoulder Elbow Surg 2007; 16, 717–721. doi: 10.1016/j.jse.2007.02.123
3. Schoch BS, King JJ, Zuckerman J, Wright TW, Roche C, Flurin P-H. Anatomic versus reverse shoulder arthroplasty: A mid-term follow-up comparison. Shoulder Elbow 2020; 13(5), 518–526. doi: 10.1177/1758573220921150
4. Sabesan VJ, Lima DJL, Yang Y, Stankard MC, Drummond M, Liou WW. The role of greater tuberosity healing in reverse shoulder arthroplasty: a finite element analysis. J Shoulder Elbow Surg 2020; 29, 347–354. doi: 10.1016/j.jse.2019.07.022
5. Schmalzl J, Jessen M, Sadler N, Lehmann LJ, Gerhardt C. High tuberosity healing rate associated with better functional outcome following primary reverse shoulder arthroplasty for proximal humeral fractures with a 135° prosthesis. BMC Musculoskelet Disord 2020; 21:35. doi: 10.1186/s12891-020-3060-8
6. Gallinet D, Clappaz P, Garbuio P, Tropet Y, Obert L. Three or four parts complex proximal humerus fractures: Hemiarthroplasty versus reverse prosthesis: A comparative study of 40 cases. Orthop Traumatol Surg Res 2009; 95, 48–55. doi: 10.1016/j.otsr.2008.09.002
7. Ackland DC, Richardson M, Pandy MG. Axial Rotation Moment Arms of the Shoulder Musculature After Reverse Total Shoulder Arthroplasty. J Bone Joint Surg Am 2012; 1886-95. doi: 10.2106/JBJS.J.01861.
8. Ohl X, Bonnevialle N, Gallinet D et al. How the greater tuberosity affects clinical outcomes after reverse shoulder arthroplasty for proximal humeral fractures. J Shoulder Elbow Surg 2018; 27, 2139–2144. doi: 10.1016/j.jse.2018.05.030
9. Garofalo R, Brody F, Castagna A, Ceccarelli E, Krishnan SG. Reverse shoulder arthroplasty with glenoid bone grafting for anterior glenoid rim fracture associated with glenohumeral dislocation and proximal humerus fracture. Orthop Traumatol Surg Res 2016; 102, 989–994. doi: 10.1016/j.otsr.2016.09.009
10. Terwee CB, de Winter AF, Scholten RJ, et al. Interobserver reproducibility of the visual estimation of range of motion of the shoulder. Arch Phys Med Rehabil 2005; 86, 1356–1361. doi: 10.1016/j.apmr.2004.12.031
11. 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. J Bone Joint Surg 2004; 86, 388–95. doi: 10.1302/0301-620x.86b3.14024
12. Wolfensperger F, Grüninger P, Dietrich M, et al. Reverse shoulder arthroplasty for complex fractures of the proximal humerus in elderly patients: impact on the level of independency, early function, and pain medication. J Shoulder Elbow Surg 2017; 26, 1462–1468. doi: 10.1016/j.jse.2017.01.021
13. Lenarz C, Shishani Y, McCrum C, Nowinski RJ, Edwards BT, Gobezie R. Is reverse shoulder arthroplasty appropriate for the treatment of fractures in the older patient?: Early Observations. Clin Orthop Relat Res 2011; 469, 3324–3331. doi: 10.1007/s11999-011-2055-z
14. Lee BK, Itamura JM. Reverse shoulder arthroplasty for proximal humerus fractures. Ann Joint 2021; 6:24. doi: 10.21037/aoj-20-15
15. Boileau P, Watkinson DJ, Hatzidakis AM, Balg F. Grammont reverse prosthesis: Design, rationale, and biomechanics. J Shoulder Elbow Surg 2005; 14, 147–161. doi: 10.1016/j.jse.2004.10.006
16. Kontaxis A, Johnson GR. The biomechanics of reverse anatomy shoulder replacement - A modelling study. Clin Biomech (Bristol, Avon) 2009; 24, 254–260. doi: 10.1016/j.clinbiomech.2008.12.004
17. Kancherla VK, Singh A, Anakwenze OA. Management of Acute Proximal Humeral Fractures. J Am Acad Orthop Surg 2017; 25, 42–52. doi: 10.5435/JAAOS-D-15-00240
18. Boileau P, Alta TD, Decroocq L, et al. Reverse shoulder arthroplasty for acute fractures in the elderly: is it worth reattaching the tuberosities? J Shoulder Elbow Surg 2019; 28, 437–444. doi: 10.1016/j.jse.2018.08.025
19. Klein M, Juschka M, Hinkenjann B, Scherger B, Ostermann PAW. Treatment of Comminuted Fractures of the Proximal Humerus in Elderly Patients With the Delta III Reverse Shoulder Prosthesis. J Orthop Trauma 2008; 22, 698-704. doi: 10.1097/BOT.0b013e31818afe40
20. Grassi FA, Zorzolo I. Reverse shoulder arthroplasty without subscapularis repair for the treatment of proximal humeral fractures in the elderly. Musculoskelet Surg 2014; 98, 5-13. doi: 10.1007/s12306-014-0321-4
21. Chun YM, Kim DS, Lee DH, Shin SJ. Reverse shoulder arthroplasty for four-part proximal humerus fracture in elderly patients: can a healed tuberosity improve the functional outcomes? J Shoulder Elbow Surg 2017; 26, 1216–1221. doi: 10.1016/j.jse.2016.11.034
22. Torrens C, Alentorn-Geli E, Mingo F, Gamba C, Santana F. Reverse shoulder arthroplasty for the treatment of acute complex proximal humeral fractures: Influence of greater tuberosity healing on the functional outcomes. J Orthop Surg (Hong Kong) 2018; 26. doi: 10.1177/2309499018760132
23. Gallinet D, Adam A, Gasse N, Rochet S, Obert L. Improvement in shoulder rotation in complex shoulder fractures treated by reverse shoulder arthroplasty. J Shoulder Elbow Surg 2013; 22, 38–44. doi: 10.1016/j.jse.2012.03.011
24. Sebastiá-Forcada E, Cebrián-Gómez R, Lizaur-Utrilla A, Gil-Guillén V. Reverse shoulder arthroplasty versus

hemiarthroplasty for acute proximal humeral fractures. A blinded, randomized, controlled, prospective study. J Shoulder Elbow Surg 2014; 23, 1419–1426. doi: 10.1016/j.jse.2014.06.035
25. Henninger HB, Barg A, Anderson AE, Bachus KN, Burks RT, Tashjian RZ. Effect of lateral offset center of rotation in reverse total shoulder arthroplasty: A biomechanical study. J Shoulder Elbow Surg 2012; 21, 1128–1135. doi: 10.1016/j.jse.2011.07.034
26. Roche C, Diep P, Hamilton M, et al. Biomechanical analysis of 3 commercially available reverse shoulder designs in a normal and medially eroded scapula. Presented at the 59th Annual Orthopaedic Research Society Meeting. San Antonio, Texas, January 26-29, 2013.
27. Simovitch RW, Zumstein MA, Lohri E, Helmy N, Gerber C. Predictors of scapular notching in patients managed with the Delta III reverse total shoulder replacement. J Bone Joint Surg Am 2007; 89, 588-600. doi: 10.2106/JBJS.F.00226
28. Nam D, Kepler CK, Neviaser AS, et al. Reverse total shoulder arthroplasty: current concepts, results, and component wear analysis. J Bone Joint Surg Am. 2010 ; 92, 23-35. doi: 10.2106/JBJS.J.00769
29. Chou J, Malak SF, Anderson IA, Astley T, Poon PC. Biomechanical evaluation of different designs of glenospheres in the SMR reverse total shoulder prosthesis: Range of motion and risk of scapular notching. J Shoulder Elbow Surg 2009; 18, 354–359. doi: 10.1016/j.jse.2009.01.015
30. Gutiérrez S, Comiskey IVCA, Luo ZP, Pupello DR, Frankle MA. Range of impingement-free abduction and adduction deficit after reverse shoulder arthroplasty. Hierarchy of surgical and implant-design-related factors. J Bone Joint Surg Am 2008; 90, 2606–2615. doi: 10.2106/JBJS.H.00012
31. Virani NA, Cabezas A, Gutiérrez S, Santoni BG, Otto R, Frankle M. Reverse shoulder arthroplasty components and surgical techniques that restore glenohumeral motion. J Shoulder Elbow Surg 2013; 22, 179–187. doi: 10.1016/j.jse.2012.02.004
32. Berhouet J, Garaud P, Favard L. Evaluation of the role of glenosphere design and humeral component retroversion in avoiding scapular notching during reverse shoulder arthroplasty. J Shoulder Elbow Surg 2014; 23, 151–158. doi: 10.1016/j.jse.2013.05.009
33. Bloch HR, Budassi P, Bischof A, et al. Influence of glenosphere design and material on clinical outcomes of reverse total shoulder arthroplasty. Shoulder Elbow 2014; 6, 156–164. doi: 10.1177/1758573214535574
34. Mollon B, Mahure SA, Roche CP, Zuckerman JD. Impact of glenosphere size on clinical outcomes after reverse total shoulder arthroplasty: An analysis of 297 shoulders. J Shoulder Elbow Surg 2016; 25, 763–771. doi: 10.1016/j.jse.2015.10.027
35. Müller AM, Born M, Jung C, et al. Glenosphere size in reverse shoulder arthroplasty: is larger better for external rotation and abduction strength? J Shoulder Elbow Surg 2018; 27, 44–52. doi: 10.1016/j.jse.2017.06.002
36. Cazeneuve JF, Cristofari DJ. The reverse shoulder prosthesis in the treatment of fractures of the proximal humerus in the elderly. J Bone Joint Surg Br. 2010; 92, 535-9. doi: 10.1302/0301-620X.92B4.22450
37. Frankle M, Marberry S, Pupello D. Reverse Shoulder Arthroplasty [electronic resource] : Biomechanics, Clinical Techniques, and Current Technologies. Springer, 1st ed. 2016;21-30.
38. Roche C, Flurin P-H, Wright T, et al. An evaluation of the relationships between reverse shoulder design parameters and range of motion, impingement, and stability. J Shoulder Elbow Surg 2009; 18, 734–741. doi: 10.1016/j.jse.2008.12.008
39. Langohr GDG, Giles JW, Athwal GS, Johnson JA. The effect of glenosphere diameter in reverse shoulder arthroplasty on muscle force, joint load, and range of motion. J Shoulder Elbow Surg 2015; 24, 972–979. doi: 10.1016/j.jse.2014.10.018
40. Giles JW, Langohr GDG, Johnson JA, Athwal GS. The rotator cuff muscles are antagonists after reverse total shoulder arthroplasty. J Shoulder Elbow Surg 2016; 25, 1592–1600. doi: 10.1016/j.jse.2016.02.028
41. Lädermann A, Edwards TB, Walch G. Arm lengthening after reverse shoulder arthroplasty: A review. Int Orthop 2014; 38, 991–1000. doi: 10.1007/s00264-013-2175-z

Correspondence:
Received: 7 December 2022
Accepted: 15 March 2023
Giacomo Roveda, MD
University of Pavia, Pavia (PV) Italy
Piazza Collegio Cairoli 1, Pavia, 27100, Italy
E-mail: giacomo.roveda01@universitadipavia.it
ORCID: 0000-0003-2387-343X