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Original Article

Impact of tuberosity treatment in reverse shoulder arthroplasty after proximal humeral fractures: A multicentre study

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ABSTRACT

Background: To assess how tuberosity treatment affects the short-term clinical outcome of patients with complex proximal humeral fractures (PHFs) treated with reverse shoulder arthroplasty (RSA).
Methods: This is a multicentre study on 90 patients affected by acute PHFs (Neer type-4/11C3.2 in 80% of patients, and a Neer type 3/11B3.2 in 20%) treated with RSA and followed at an average of 34 months. Patients were divided into two groups (reconstructed and non-reconstructed tuberosity) according to the surgical fixation of the tuberosities. Then, the "reconstructed tuberosity" was divided into "healed" and "non-healed" groups. All patients were clinically evaluated in terms of ROM and strength in elevation, as well as with 0–10 numerical rating scale (NRS), Constant and Murley Score (CMS), DASH Score, and EQ-VAS. X-rays in anteroposterior and Neer views were performed.
Results: Based on the status of the tuberosities, 18.9% were non-reconstructed (17 patients) and 81.1% were reconstructed (73 patients): out of these, 11 were correctly healed, 42 healed with malposition, and 20 were reabsorbed. Instability was found in 2/73 patients in the reconstructed group, and in 4/17 patients in the non-reconstructed group. NRS (1.4 vs 0.5), DASH (23.1 vs 13.9), and EQ-VAS (78.1 vs 83.7) scores had better final values in the non-reconstructed group ($p < 0.05$). However, the non-correctly healed tuberosity group (excision + resorption + malposition/migration) showed worse strength, as well as clinical scores when compared to the correctly healed tuberosity group.
Conclusion: RSA ensures satisfactory functional results for PHFs. Patients with a successfully reconstructed tuberosity have an overall better outcome. However, in this series most of the reconstructed cases presented tuberosity reabsorption, malposition, or migration, which led to lower results. Thus, tuberosity reconstruction must be carefully considered and tuberosity reabsorption or migration factors should be investigated, to optimize tuberosity reconstruction and provide to a higher number of patients a better outcome of RSA for the treatment of PHFs.

1. Introduction

Proximal humeral fractures (PHFs) are the third most common fracture type, representing approximately 5% of all fractures, with an increasing incidence due to the ageing of the population [1]. After a PHF both conservative and surgical treatments can be performed, with the second preferred in case of displaced and complex fractures, especially in patients over 70 years old [2,3]. Fracture

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fixation in the elderly population has always been at risk of dangerous complications and the results are still not always satisfactory [4]. Another option is hemiarthroplasty, whose outcomes are very variable, with the main determinant being the healing of the tuberosities due to their role in the attachment of rotator cuff tendons [5]. In fact, a greater range of motion (ROM) and higher patient satisfaction are seen in patients with healed tuberosities, whereas poor results are reported in case of tuberosity resorption, malunion or nonunion [5–8]. On the other hand, to achieve tuberosity healing, surgeons need to fix the tuberosities to the prosthesis, increasing technical complexity and surgical time. Moreover, tuberosity healing is quite unpredictable, as it depends on multiple factors such as abnormalities in the rotator cuff, bone quality, and fractures characteristics. In particular, the outcome of hemiarthroplasty is jeopardized by the unsatisfactory tuberosity healing in the elderly population, whose bone quality and rotator cuff conditions are often compromised, thus suggesting the need for a more suitable solution [6].

In this light, reverse shoulder arthroplasty (RSA) showed a better functional outcome than hemiarthroplasty for the treatment of PHFs, with more consistent and predictable results [9]. The necessity of tuberosity healing after RSA is still debated, as RSA is able to improve function for patients with rotator cuff-deficient shoulders [10]: some authors suggest good clinical results after removing both tuberosities [9,11–13], while others report a better functional and clinical outcome after tuberosity reconstruction and healing [14,15], as in the recent study of Boileau et al. in which complications such as instability, infection, and implant loosening have been reported when the tuberosities do not heal around the reverse stem. These contrasting findings question the real need for tuberosity fixation when treating complex PHFs with RSA. The evidence regarding the influence of the tuberosity healing on the outcomes of RSA is still weak [16], thus there is no overall agreement among shoulder surgeons on its relevance and therefore on the need to increase surgical complexity and time for tuberosity fixation when addressing PHFs [17]. More data are needed to provide new evidence to understand whether a more complex and longer surgery to stably fix the tuberosity to RSA is justified by a better clinical outcome in patients with healed tuberosity.

The aim of this study is to assess the real benefit of tuberosity treatment in RSA for complex PHFs.

2. Materials and methods

2.1. Patients selection

This multicentre, level 3 retrospective study was conducted at the authors' institutions after approval given by the local Ethical Committee. Two hundred and two patients were retrieved from the hospitals registers (Fig. 1). Inclusion criteria were: patients treated for acute 3- and 4-part PHF at the study sites between 2015 and 2019; treatment with RSA; ability to obtain the informed consent. Exclusion criteria were: death, pathological fracture, previous operation on the same shoulder, irreparable rotator cuff tear, previous fracture of the operated arm, and postoperative complications. Ninety patients affected by an acute 3- and 4-part PHF treated with RSA at the study sites between 2015 and 2019 were evaluated after informed consent was obtained.

Ninety patients completed the follow-up visit at a minimum of 12 months (mean follow-up 34 months, range 12–67 months). The mean age at surgery was 74 years (range 51–86 years); 10 patients were <65 years old, and of them, two were <60 years old. 78% of patients were women and 22% men, 44 patients (48.9%) had osteoporosis, and 14 patients (15.6%) had diabetes. The injured shoulder was on the dominant side 64% of the time. PHF pattern was a Neer type-4/11C3.2 in 80% of patients, and a Neer type 3/11B3.2 in the others. Three different models of RSA were used, all with a medializing design: 46 (51.1%) Lima SMR™ (Lima Corporate Spa, Villanova di San Daniele del Friuli, Italy), 36 (40.0%) DELTA XTend™ (DePuy Synthes, J&J Medical Devices, Raynham MA, U.S.), and 8 (8.9%) Zimmer Trabecular™ (Zimmer Biomet Inc., Warsaw, Indiana, U.S.). Of these, a cemented humeral stem was used in 30 implants (33.3%), while a cementless stem was used in the remaining 60 (66.7%). In every case, surgery was performed in beach chair positioning, under general anaesthesia, and using a deltopectoral approach. The patient was placed with anterior and posterior shoulder parts free of obstacles. Before starting the operation, bony landmarks of the shoulder were located, such as acromion, clavicle, and coracoid process. An oblique skin section was performed in the anterior side of the shoulder near the DP groove, from coracoid apophysis to the deltoid muscle. Then, the cephalic vein was recognized and withdrawn laterally. The subacromial adhesions were unleashed, and the clavipectoral aponeurosis was cut out. Afterwards, the biceps tendon was recognized and subsequently tenotomized. The subscapularis was released from the lesser tubercle, letting a tissue segment for reconstruction; the supraspinatus was reattached only if the tuberosity was reconstructed. Following humerus preparation, the glenoid was revealed and prepared, then the implant was placed slightly lower and posterior to the marked center. The humeral stem was placed with 10° of retroversion; regarding its height, the positioning is made by evaluating the deltoid tension with the temporary implants. The decision on tuberosity reconstruction was made based on the integrity of the tuberosity, thus multi-fragmentary tuberosities were excluded from the reconstruction. All the tuberosities were fixed by sutures.

The postoperative rehabilitation program was performed by a professional physiotherapist and was as follow: six weeks of free mobilization, based on pain, with limitation of the external rotation up to 45°; sling or brace day and night for the first three weeks; physiotherapy 2 times a week at least with the objectives of gradually improve the range of motion and strengthen the deltoid muscle. No lifting objects, no driving and no weight on the operated limb. After 6 weeks, a clinical visit by the operating surgeon with an X-ray and then the decision on how to proceed based on the clinical and radiographic status of the shoulder and the functional demands of the patient.

2.2. Patient evaluation

At final follow-up, shoulder ROM (internal rotation was measured in accordance to the 0–6 points scale of the Constant and Murley Score) and strength in elevation were assessed by a physician not involved in the treatment decision nor in the surgical procedure; for the strength assessment, the IsoForceControl® EVO2 digital Dynamometer was used. Function was evaluated with a 0–10 numerical rating scale (NRS) [18], Constant and Murley Score [19], DASH Score [20], and EQ-VAS [21]. An X-ray in anteroposterior and Neer views was performed; two independent surgeons assessed the position and/or the resorption of the tuberosity and the presence of heterotopic ossifications. Based on previous studies, the correct healing of the reconstructed greater tuberosity was defined when tuberosity was visible on the X-ray in anteroposterior projection and Neer projection, in continuity with the diaphysis and at the level of the proximal apex of the humeral stem or lower no more than 5 mm [14,22].

2.3. Statistical analysis

Data were analyzed using SPSS 24.0 software (SPSS Inc., IL, U.S.). Independent and paired samples t-tests were run for all the

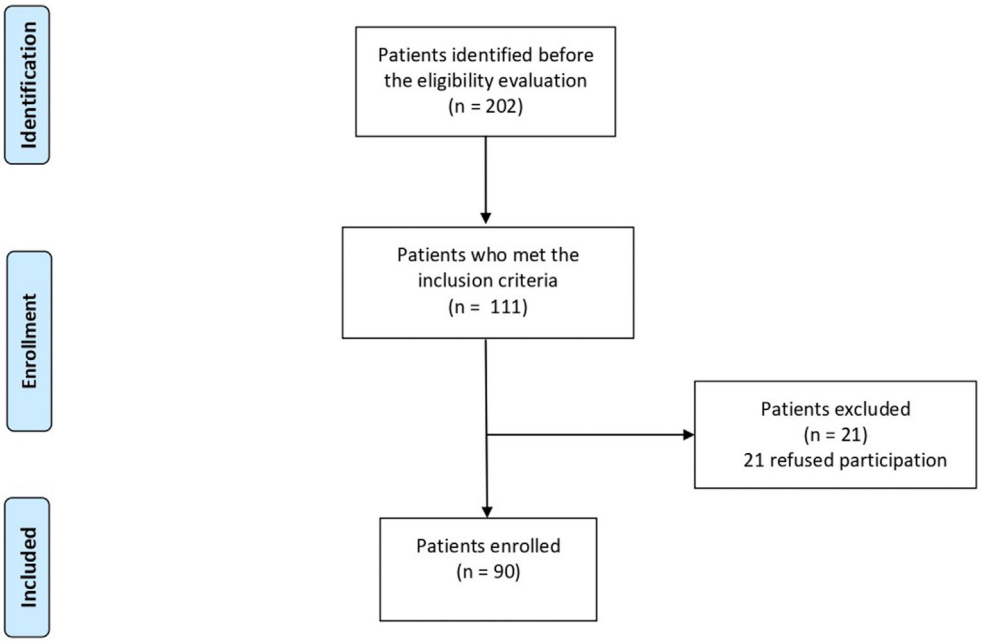

Fig. 1. Flowchart of the patients selection process.

parametric tested variables. Correlations were investigated with regression analysis. Significance was set at $p < 0.05$.

3. Results

3.1. Functional outcomes

For demographic data of the healed and non-healed groups, see Table 1. At a mean follow-up of 34 months, the overall results of the 90 included patients were a mean NRS of 1.3 ± 1.7 points, a mean CMS of 65.7 ± 16.3, a mean DASH of 21.4 ± 14.9, and a mean EQ-VAS of 78.1 ± 12.7. ROM showed mean values of 134.6° ± 28.4° for active anterior elevation, 122.9° ± 29.6° for abduction, 14.3° ± 8.6° for external rotation, 3 ± 2 points (waist/L3) for the internal rotation, and the mean strength in elevation was 6.9 ± 2.9 kg.

3.2. Radiological findings

Two main groups were distinguished based on the immediate post-operative status of the tuberosities (Fig. 2): reconstructed (73 patients – 81.1%) or excised (17 patients – 18.9%). The first group of reconstructed tuberosities was divided into two groups based on the follow-up status of the tuberosities: healed (53 patients – 72.6%) or reabsorbed (20 patients – 27.4%). Among the healed tuberosities, 11 patients (20.8%) presented a correct position at follow-up, while final malposition was found in 19 patients (35.8%). Migration was found in 23 patients (43.4%) (Fig. 3).

At follow-up X-ray, heterotopic ossifications occurred in 25 patients (27.8%) and a statistically significant difference for the abduction was found in presence of heterotopic ossifications ($p = 0.028$; 111.7° ± 26.7° with ossifications vs 127.1° ± 19.8° without ossifications).

3.3. Impact of tuberosity reconstruction and healing

There was no significant difference between the reconstructed and non-reconstructed tuberosity in terms of ROM and strength in elevation. There was no significant difference in CMS, while NRS, DASH, and EQ-VAS scores were found to have better final values in the non-reconstructed tuberosity group ($p < 0.05$). The difference measured in terms of operative time did not reach statistical significance. Outcomes of reconstructed and non-reconstructed tuberosities are seen in Table 2.

Out of the 73 patients with tuberosity reconstruction, resorption occurred in 20 patients (27.4%), while in the remaining 53 patients (72.6%) there was healing of the tuberosities. These groups had

Table 1
Outcome of healed and non healed tuberosity groups.

	Healed tuberosity	Non healed tuberosity
	Mean	Mean
Age	73.5 ± 6.5	74.1 ± 6.7
Gender	F: 73.6%, M: 26.4%	F: 85.3%, M: 14.7%
Diabetes	15.1%	14.3%
Osteoporosis	39.6%	51.4%
Shoulder	R: 54.7%, L: 45.3%	R: 47.1%, L: 52.9%
Fracture type	N4: 79.2%, N3: 20.8%	N4: 79.4%, N3: 20.6%
Implant	Lima 47.2%, Delta 41.5%, Zimmer 7.5%, Aequalis 3.8%	Lima 55.9%, Delta 35.3%, Zimmer 5.9%, Aequalis 2.9%
Days to surgery	6 ± 6	6 ± 5
Surgery (min)	116.8 ± 31.8	111.5 ± 37.7

F, female; M, male; R, right; L, left; N, number; min, minute.

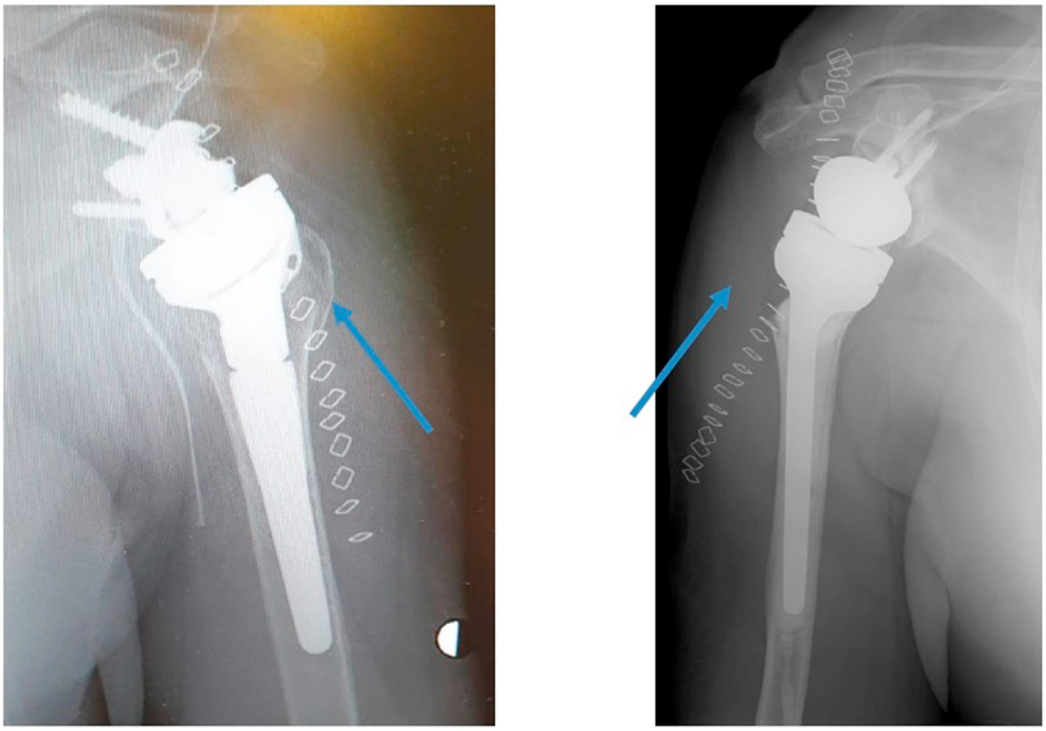

Fig. 2. Postoperative X-ray of RSA: 2a, on the left, anatomical reconstruction of tuberosity. 2b, on the right, excised tuberosity.

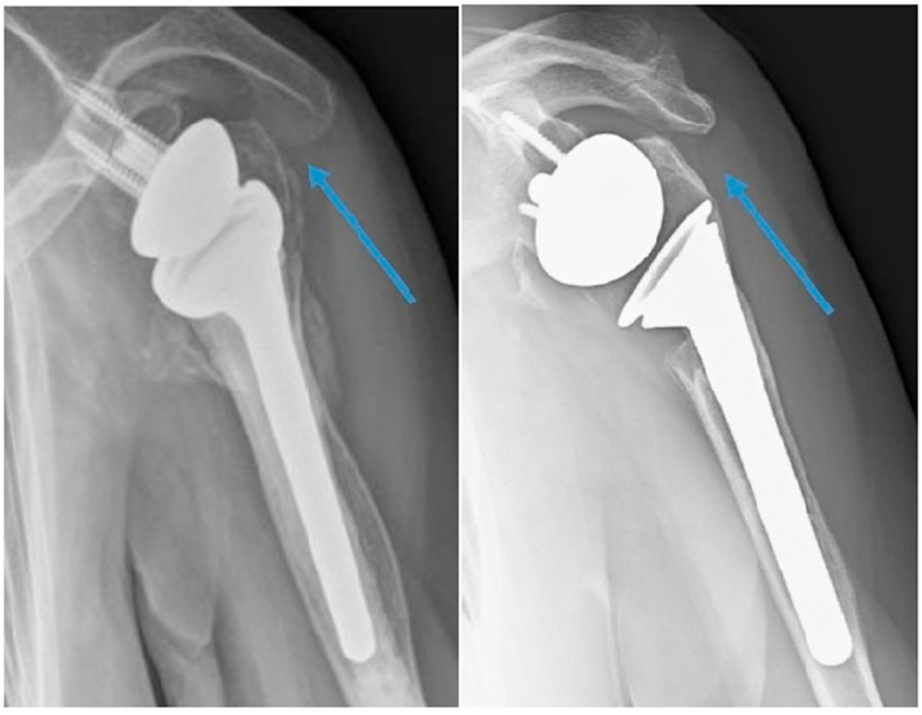

Fig. 3. Postoperative X-ray of RSA: 3a, on the left, malposition of tuberosity. 3b, on the right, final migration of tuberosity.

similar ROM values, except for intra-rotation which was higher in the reabsorbed tuberosity group ($p = 0.042$). On the other hand, strength had higher values in the healed tuberosity group ($p = 0.022$). All the functional scores beside EQ-VAS presented better values for the group of healed tuberosity ($p < 0.05$). Outcomes of reabsorbed and non-reabsorbed tuberosities are seen in Table 3.

When considering the group of migrated and non-migrated tuberosities, there was no statistically significant difference for ROM and strength in elevation. On the other hand, the functional

Table 2
Outcome of reconstructed and non reconstructed tuberosity groups.

	Reconstructed tuberosity	Non reconstructed tuberosity	*P* value
	Mean ± SD	Mean ± SD	
Elevation	134.1° ± 28.3°	136.6° ± 29.4°	0.756
Abduction	123.5° ± 29.9°	120.6° ± 29.4°	0.728
Extrarotation	14.5° ± 8.2°	13.4° ± 10.4°	0.65
Intrarotation	3.4 ± 1.3	3.0 ± 1.4	0.292
Strength (kg)	7.1 ± 2.9	6.0 ± 2.8	0.166
NRS	1.4 ± 1.8	0.5 ± 0.1	0.042
CMS	65.5 ± 16.4	66.7 ± 16.5	0.787
DASH	23.1 ± 15.4	13.9 ± 9.9	0.026
OSS	39.5 ± 8.2	44.1 ± 5.3	0.035
EQ-VAS	78.1 ± 13.3	83.7 ± 8.7	0.041
Surgery time (min)	112.9 ± 35.1	105.7 ± 30.7	0.447

NRS, numerical rating scale; CMS, Constant and Murley Score; DASH, disability of hand and shoulder; EQ-VAS, EuroQol Visual Analogue Scale.

scores presented a lower outcome when tuberosity migration was present, as seen in NRS ($p = 0.002$, 2.4 ± 2 in migrated vs 0.9 ± 1.4 in non-migrated), CMS ($p = 0.009$, 60.1 ± 15.9 in migrated vs 70.6 ± 14.8 in non-migrated), DASH ($p = 0.001$, 29.5 ± 14 in migrated vs 17.2 ± 12.1 in non-migrated), and EQ-VAS ($p = 0.001$, 72.2 ± 13.9 in migrated vs 82.8 ± 10.5 in non-migrated).

When comparing correctly healed tuberosities with the non-healed tuberosity group (excision, reabsorption, and migration) a statistically significant improvement for correctly healed tuberosities was found for VAS pain ($p = 0.049$) and Oxford Shoulder Score ($p = 0.016$).

3.4. Postoperative complications

Out of the 202 patients identified from hospital registries before the elegibility evaluation, eleven patients had major complications that required a secondary surgery, and of them, seven were in the reconstructed tuberosity group, and four were in the non-reconstructed one. Six patients due to instability (two with reconstructed tuberosity), three due to aseptic loosening (two of the humerus and one of the scapula; all of this had reconstructed tuberosity), and two due to prosthetic infection (both with reconstructed tuberosity).

4. Discussion

The main finding of this study is that tuberosity reconstruction provides an advantage in the treatment of PHFs. However, there are several factors jeopardizing the results, since many patients did not reach correct healing and thus did not benefit from the procedure due to malposition, migration, or tuberosity reabsorption.

Table 3
Outcome of reabsorbed and healed tuberosity groups.

	Reabsorbed tuberosity	Healed tuberosity	*P* value
	Mean ± SD	Mean ± SD	
Elevation	127.9° ± 32.1°	132.9° ± 26.4°	0.357
Abduction	120.9° ± 33.8°	122.0° ± 27.8°	0.747
Extrarotation	13.4° ± 6.6°	14.9° ± 8.5°	0.435
Intrarotation	3.8 ± 1.2	3.2 ± 1.2	0.042
Strength (kg)	6.6 ± 2.6	7.5 ± 2.7	0.022
NRS	2.2 ± 1.5	1.2 ± 1.7	0.009
CMS	58.1 ± 17.6	67.9 ± 15.0	0.010
DASH	31.5 ± 16.3	19.9 ± 13.8	0.001
OSS	34.9 ± 8.6	40.9 ± 7.3	0.001
EQ-VAS	79.4 ± 13.2	79.5 ± 12.6	0.292
Surgery time (min)	104.0 ± 39.7	111.9 ± 32.1	0.165

NRS, numerical rating scale; CMS, Constant and Murley Score; DASH, disability of hand and shoulder; EQ-VAS, EuroQol Visual Analogue Scale.

The study findings are of particular interest since this series presents patients' data consistent with the literature about PHFs [1,23], thus representing the type of patients commonly facing the issue investigated: 78% of patients were women, and the mean age at surgery was 74 years old. Almost all traumas were low-energy, mostly for falls from the patient's own height. Both upper limbs were equally affected, the majority of fractures being Neer 4 parts. The literature did not show differences in ROM and functional outcome between patients with three parts and four parts fractures; this allows to conclude that RSA is a reliable treatment that standardizes functional outcomes no matter the initial severity of the fracture [8], with consistent results supporting the enrolment in this study of both types of fractures [15,16,24]. Also, no difference was previously reported between cemented and uncemented prosthesis stems [25], as confirmed by this study. More controversial are instead literature data about the need for tuberosity reconstruction.

Some studies consider the tuberosities anatomical reconstruction and their healing as fundamental for a good functional result and quality of life, noting overall improvements in patients with anatomically re-inserted and consolidated tuberosities when compared to patients with the same fractures pattern but excised tuberosities [25], as for the study of Boileau et al. conducted in 2018 on 38 patients [14]. However, most of the current literature reports a statistically significant improvement only in external rotation in case of reinserted and consolidated tuberosities, with functional results not different from the group with non-reinsertion or malposition [12,17,26–28]. Moreover, a systematic review of Jobin et al. [17] suggested that tuberosity reconstruction is not essential for a good clinical outcome, although improving extra-rotation, and more recently a multicentre study of Reuther et al. [16] confirmed no difference in ROM, CMS, and operative time with and without tuberosity reconstruction. This study provides evidence apparently showing lack of benefits: tuberosity reconstruction did not influence the functional outcome and the quality of life, with no statically significant difference for ROM, strength in elevation and CMS, while NRS, DASH, and EQ-VAS even had better final values in the non-reconstructed tuberosity group. Thus, almost no advantages have been demonstrated for a procedure introducing further surgical complexity and time, with consequently higher costs and infectious risks, even though this series did not allow demonstrating significant differences in these aspects. However, it is fundamental to notice that the correct healing of reconstructed tuberosities guarantees better results in terms of pain and function (evaluated through the Oxford Shoulder Score). Thus, further studies should evaluate the factors influencing proper tuberosity healing, aiming

to select the patients eligible for tuberosity reconstruction in order to dedicate the necessary surgical time for this procedure only to those patients who can benefit from a better outcome of RSA for the treatment of PHFs. One aspect already largely discussed by the literature, and for which there is no clear consensus, is whether the tuberosity reconstruction provides less instability; in the present study, it appears that the tuberosity reconstruction could determine fewer cases of instability. Thus, a correctly healed tuberosity could represent an advantage also on this aspect. Overall, this study documents the need to optimize the tuberosity treatment in order to offer to the highest number of patients possible a better outcome.

This series was further investigated to identify possible aspects in the tuberosity healing influencing the study findings. The radiological follow-up of this study showed a consolidation rate of 72.6% for reconstructed tuberosities: which is broadly in line with the current literature. Schmalzl et al. reported 77% [29] and Formaini et al. 88% [26], with the relatively wide range of tuberosity consolidation being likely attributable to the different methods of fixation and the different prosthetic implants used [12]. The radiological follow-up also allowed distinguishing patients with healed tuberosities or with reabsorbed tuberosities, who presented no difference in terms of abduction, elevation, and external rotation, but a statistically significant difference for internal rotation in favour of reabsorbed tuberosities, while a significant difference was found in favour of healed tuberosities in terms of elevation, strength, as well as clinical scores investigating symptoms and function, i.e. NRS, CMS, and DASH scores. All the functional scores presented better values for the group of tuberosity healing versus reabsorbed ones. No consensus in the literature is seen for the implication of a correctly consolidated tuberosity: Gallinet et al. [27] reported better DASH and CSS for consolidated tuberosities, while Chun et al. [12] showed no difference in functional outcomes and quality of life for reconstruction or resorption.

In this light, the group of reconstructed but migrated tuberosities was independently evaluated: no significant difference was obtained for the ROM and strength in elevation, while a significant difference was found in favour of non-migrated tuberosities in all functional scores. This could lead to the conclusion that a secondary breakdown of the reconstructed tuberosity would imply worsening of the functional outcome and quality of life, supporting the need for improvements in surgical reconstruction methods to have healing with better position and outcomes.

This series also allowed drawing other interesting conclusions. Heterotopic ossifications were seen in 27.8% of patients and caused a statistically significant decrease in abduction. This data is partially consistent with that of Verhofste et al. [30], who found a 29.5% heterotopic ossification rate, although no long-term clinical impact was seen. Also, Sperling et al. [31] describe heterotopic ossifications after RSA as infrequent and, if present, typical of the early post-op period and not influencing the final clinical outcome. Thus, further studies should clarify the real impact of ossifications on the final outcome. Finally, considering comorbidities, no influence on functional outcomes and quality of life was seen for diabetes. Contrarily, osteoporosis was associated with advanced age at the time of surgery, and worst extra-rotation at final follow-up in comparison to non-osteoporotic patients. As largely discussed in previous literature, osteoporosis increases at the increase of age; similarly, the reduction in extra-rotation in the elderly is likely due to reduction of muscular tropism (especially for infraspinatus and teres minor muscle) [23]. Future studies should explore the role of osteoporosis and other patients' characteristics on the final outcome and identify possible candidates where tuberosity reconstruction might prove more beneficial with respect to the general population.

This study has several limitations, mainly related to the intrinsic nature of a retrospective multicenter study: different prosthetic implants, operators and tuberosity reconstruction techniques. Also, some patients could not be enrolled because of death or inability to attend to the follow-up. A comparison between different prostheses was not feasible, although this limitation is mitigated by the recent systematic review of O'Sullivan et al. [32] which compared different RSA concluding that models with 135° humeral inclination ensure a higher healing rate. Besides, it was not possible to investigate the healing of the lesser tuberosity as well, being not always clearly visible on X-rays; a CT follow-up scan could allow a more accurate evaluation of the lesser tuberosity. Finally, a further limitation was the radiographic measurement of the tuberosity correct position. Only for anatomical prosthesis some authors have defined the correct position of the major tuberosity on the AP X-ray as visible and positioned 5–10 mm below the apex of the prosthetic head [6]. In contrast, for RSA there are few and limited studies about radiographic evaluation of tuberosities, none of these using precise cut-offs based on anatomical studies. Therefore, there is no objective but only arbitrary methods to evaluate the healing of reconstructed tuberosities [6,9,12,15,16,27,29]. Despite the abovementioned limitations, this multicentre study presents a large series of patients evaluated at mid-term follow-up and allowed to draw important and clinically relevant conclusions on the surgical treatment of PHFs with RSA.

5. Conclusions

RSA ensures satisfactory functional results for PHFs. Patients with a successfully reconstructed tuberosity have an overall better outcome. However, in this series, most of the reconstructed cases presented tuberosity reabsorption or migration, which led to lower results.

Thus, tuberosity reconstruction must be carefully considered, and tuberosity reabsorption or migration factors should be investigated, to optimize tuberosity reconstruction and provide to a higher number of patients a better outcome of RSA for the treatment of PHFs.

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Declaration of competing interest

No author disclosures or conflicts of interest are present for this work, by any author.

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