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REVIEW ARTICLE

Tuberosity healing after reverse shoulder arthroplasty for complex proximal humeral fractures in elderly patients—does it improve outcomes? A systematic review and meta-analysis

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Background: Reverse shoulder arthroplasty (RSA) is being increasingly used for complex, displaced fractures of the proximal humerus in older patients. Anatomic tuberosity healing in RSA has been recognized to restore better shoulder function. We compared the reported clinical and functional outcomes of RSA in proximal humeral fractures with and without tuberosity healing.
Methods: We performed a systematic review of literature based on Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines and searched MEDLINE, CINAHL, Embase, and Cochrane Central Register of Controlled Trials. We included all studies with RSA for proximal humeral fractures in patients older than 60 years and compared outcomes based on tuberosity healing with minimum follow-up of 12 months.
Results: Seven studies met the inclusion criteria. A total of 381 patients (382 shoulders) were identified. There were 53 men (18.3%) and 236 women (81.7%), with mean age of 76.83 years (range, 74-81 years). Mean follow-up duration was 29.84 months (range, 24-90 months), and the mean rate of greater tuberosity healing was 70.5%. Patients with healed tuberosity had significantly better active forward flexion (134.1° vs. 112.5°, $P < .05$), abduction (114.8° vs. 95.1°, $P < .05$), external rotation with elbow by the side (27.8° vs. 7.6°), and mean Constant score (63.5 vs. 56.6, $P < .05$) than with those with nonhealed tuberosity.
Conclusion: The RSA group with healed greater tuberosity showed better range of motion, especially forward flexion and external rotation and Constant scores, compared with the nonhealed greater tuberosity group. Tuberosity healing may influence overall shoulder function after RSA for proximal humeral fractures in the elderly, and this needs verification with future prospective studies.

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Keywords: Reverse shoulder arthroplasty; proximal humerus fracture; elderly patients; tuberosity healing; tuberosity repair; outcomes

Proximal humeral fractures are the third most commonly encountered fracture after hip and distal radius fractures in older adults, and the incidence increases with age, especially in patients who are still active.[3,5,11] Some authors suggest the choice of treatment should be guided by variables such as patient age, functional status, comorbidities, fracture pattern, and classification.[48] Most proximal humeral fractures are treated nonoperatively, but displaced or comminuted fractures may be treated surgically to prevent chronic pain and maximize functional outcomes.[47] These more severe fractures account for 5% to 15% of all proximal humeral fractures.[10]

Several surgical options are available for management of complex proximal humeral fractures. Osteosynthesis with stabilization and fracture fixation has been recommended,[20,58] but poor bone quality in elderly patients may lead to high complication rates.[15] Some authors report good pain relief and functional recovery with shoulder hemiarthroplasty (HA).[2,8,16,22,50] Others have demonstrated poor functional results with nonanatomic consolidation or nonunion or resorption of tuberosity and rotator cuff deficiency.[6,22,44]

The reverse shoulder prosthesis (RSA) has recently become a popular alternative to HA and has been increasingly used for management of complex proximal humeral fractures in elderly individuals.[41] RSA design does not rely on a functioning rotator cuff, rather principally relies on the functional value of the deltoid muscle.[7,18,31,56] RSA biomechanically improves the deltoid lever arm by lowering the humerus and medializing the center of rotation of the shoulder, thereby changing the vertical balance of the shoulder. Several authors[9,24,33] have demonstrated satisfactory outcomes after RSA in the treatment of osteoporotic complex proximal humeral fractures. Multiple studies[19,52,60] in recent times have shown better results with RSA compared with HA in proximal humeral fractures. Although, RSA has shown satisfactory clinical and functional outcomes, there are 2 major concerns with its use: scapular notching and compromised external and internal rotation thereby impairing function and patient satisfaction.[12,18,25,51]

Recently, healing of tuberosity in RSA has been observed to show better outcomes in improved active forward flexion,[1] external rotation,[1,24] and external rotation strength.[39] With gaining popularity of RSA in proximal humeral fractures, there is emphasis on tuberosity repair to restore better shoulder function. There are different techniques of tuberosity repair, and multiple new techniques have been described in an effort to increase the likelihood of tuberosity healing.[36,38,39]

Also, in recent times there have been certain modifications in implant design to allow for suture fixation to stem and metaphyseal "fins" to resist rotational stress and large surfaces for tuberosity healing with bone graft void and ingrowth surfaces.[36,40] Furthermore, structural bone grafts have also been used to enlarge the area for tuberosity repair and healing potential,[39] whereas partially cemented techniques for the humeral stem have been proposed to shield the intact proximal humerus and tuberosity from cement-induced thermal necrosis that may occur at the junction of the cement mantle and the tuberosity.[38,45]

The purpose of this systematic review was to compare clinical and functional outcomes after RSA in elderly patients with complex proximal humeral fracture with healed greater tuberosity (HT) or nonhealed greater tuberosity (NHT). We hypothesized that RSA with a HT will provide better clinical outcomes in range of motion (ROM) and functional outcome score.

Materials and methods

We systematically reviewed the literature according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines with a PRISMA Checklist (Supplementary Appendix S1) and algorithm.[46] All studies were included (Supplementary Appendix S2) after meeting the following criteria:

1. Population with a mean age of 60 years and older who sustained a proximal humeral fracture,
2. Treatment with reverse shoulder replacement,
3. A comparison group including treatment with HA or no comparison group,
4. Articles with assessment of healing of tuberosity,
5. A minimum of 12 months of follow-up,
6. Reported outcomes measures or scores and complications, and
7. Any study design.

We assessed each article for reported clinical outcome measures, including ROM, specifically forward flexion, abduction, external and internal rotation, and functional outcomes assessed by the Constant-Murley score (CMS),[17] American Shoulder and Elbow Surgeons Shoulder (ASES) score,[32] Disabilities of Arm, Shoulder and Hand (DASH) score,[43] and visual analog scale (VAS) for pain.[42] We also assessed reported complications, including infection, nerve injury, fracture, dislocation, and radiologic findings such as tuberosity healing and scapular notching.

The search was performed up to March 1, 2018. A detailed search was made for all journals, and all studies relevant to topic were analyzed. We screened the MEDLINE, Embase, CINAHL, Cochrane Central Register for Controlled Trials databases (Supplementary Appendix S3). The search was limited to the English language, and articles in other languages were excluded. No limits date or year or word variants were applied.

A manual search was made for recent publications or articles in journals not indexed by databases that might be missed,

abstracts from scientific meetings, and trial registries. We also used Web of Science to facilitate the reference review. Two independent reviewers (N.P.J. and S.S.M.) separately conducted the search. A structured search strategy was used to access both published and unpublished work. We used Medical Subject Headings terms to get specific subject headings and included use of keywords to search the studies for review. The keywords that were used included elderly patients, proximal humerus fracture, fracture of proximal humerus, reverse shoulder arthroplasty, reverse prosthesis, reverse shoulder replacement, tuberosity repair, tuberosity healing, CMS, complications, and ASES score. We used the Boolean operator "or" and subsequently "and" to consolidate the search results.

The selection process was first piloted, which involved applying inclusion criteria to a few sample papers to ascertain whether our predefined criteria were adequate for appropriate interpretation and selection of studies. Articles were initially screened for relevance by title and abstract. We excluded articles without an abstract and obtained the full-text article if the abstract did not allow the investigators to assess the defined inclusion and exclusion criteria. A cross-reference search of selected articles was performed to obtain other relevant articles.

Two independent investigators (N.P.J. and S.S.M.) separately assessed each article that met the inclusion criteria. Discrepancies were resolved by discussion to reach a consensus, and if disagreement persisted, an additional independent third reviewer (R.D.) was conferred. All articles had to be published in peer reviewed journals. We excluded case reports, conference abstracts, posters, studies on animals, cadavers, or in vitro, tumor prosthesis, instructional course lectures, and letter to editors.

We collected relevant data from the articles that met the inclusion criteria after assessment of full text. We extracted all data (Supplementary Appendix S4) related to study methodology, patient demographics, fracture types, treatment methods, implant used, assessment of tuberosity healing, and related outcomes and complications. Data extraction was undertaken by 2 independent reviewers (N.P.J. and S.S.M.) separately on a standardized data collection form formulated after discussion and undertaking pilot data collection. Missing data pertaining to these parameters were excluded from this systematic review.

We assessed the methodological quality of studies included in review using the modified Newcastle Ottawa scale[61] (Supplementary Appendix S5, *a*) and randomized controlled trials based on Cochrane Collaboration back review (Supplementary Appendix S5, *b*). All studies were independently reviewed by 2 reviewers (N.P.J. and S.S.M.) to evaluate the methodological quality. In case of disagreement, an attempt to resolve the dispute was done by discussion, and an additional independent third reviewer (R.D.) was conferred if consensus could not be reached.

Outcome assessment

The primary outcomes studied were tuberosity healing and active ROM, particularly forward flexion and external rotation measured in degrees. Secondary outcome measures included functional assessments: CMS and ASES, DASH, VAS, Simple Shoulder Test (SST), and Subjective Shoulder Value (SSV) scores. Postoperative complications were assessed including infection, dislocation, revision surgery, and nerve injury. We also examined the reported incidence of scapular notching after RSA.

Statistical analysis

Continuous variables are reported as mean and standard deviation or range, and categorical variables are reported as frequency or percentages. We used the weighted mean difference (WMD) to analyze continuous outcomes in ROM and functional outcomes, if they were reported in 2 or more studies, and standardized mean difference (SMD) for outcomes reported in all studies. $P < .05$ was considered statistically significant. The standard deviation was not reported in many studies, so we used P values to compute the standard error for the difference of the means, followed by calculation of standard deviation, and finally, mean differences were derived from the same. We used RevMan 5.3 (Cochrane, London, United Kingdom) to summarize the findings of controlled studies using random effect models.

Results

We identified 1102 articles through the search engine. Removal of duplicates after screening for eligibility yielded 918 studies. After screening of titles and abstracts, we retrieved 94 articles for the full-text review. Further full-text review shortlisted 12 papers, and 5 of these were excluded after further detailed review for outcomes based on tuberosity healing. Finally, 7 articles[14,19,24,27,30,53,59] fulfilled all criteria as predetermined and were considered for in-depth analysis (Fig. 1). These included 1 randomized controlled trial,[53] 1 prospective comparative study,[19] 1 retrospective case-control multicenter study,[14] 1 retrospective case control,[24] and 3 retrospective cohort studies.[27,30,59] The study selection process is summarized in the PRISMA flow diagram (Fig. 1).

Demographics

We identified 381 patients and 382 shoulders (1 bilateral) from the reviewed studies that were treated with RSA as primary surgical management for proximal humeral fracture. Of these, 68 patients (17.84%) were lost to follow-up, including 22 from death, 19 declined participation or moved out of the area, 5 were care home residents, and 16 were excluded due to incomplete data and 6 for other reasons. Therefore, 313 patients (82.15%) with 314 shoulders (82.19%) were available for final follow-up. There were 53 men (18.3%) and 236 women (81.7%), with a male-to-female ratio of 0.2. Sex distribution of the remaining 24 patients (7.6%) was not reported (Table I).

The weighted mean age of patients was 76.83 years (range, 74-81 years). The dominant arm was involved in 40 patients (23.9%) but was not reported in 244 patients (77.7%). The laterality was reported in only 1 study,[30] with 32 right shoulders (61.5%) and 20 left shoulders (38.5%), including 1 patient with bilateral shoulders, whereas the side was not reported in remaining 262 patients (83.4%). All included studies reported mean interval between injury and surgery, which was 6.5 ± 4.2 days (range 0-15 days). The weighted

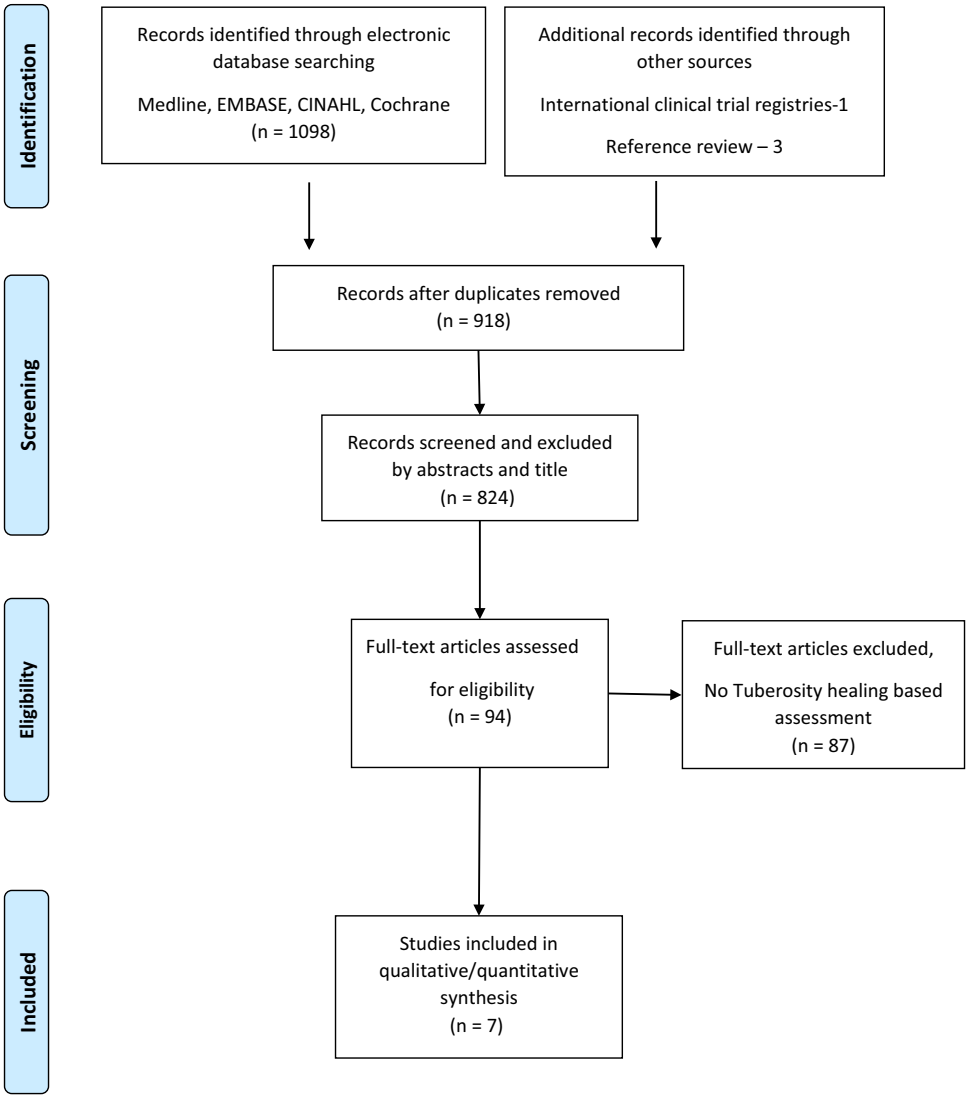

Figure 1 Flow diagram depicts study selection process.

mean duration of follow-up was 29.84 months (range, 24-90 months).

Fracture classification

Although different classification systems are used for proximal humeral fractures, including Neer,[49] Duparc,[21] Arbeitsgemeinschaft für Osteosynthesefragen (AO)-Müller, and Orthopaedic Trauma Association,[26] only 3 studies[30,53,59] reported the fracture types (Table II). The Neer classification system was used to classify 124 fractures (39.49%), with 16 (12.90%) 3-part fractures, 93 (75%) 4-part fractures, and 10 (8.06%) head-splitting fractures. None of the papers reviewed mentioned fracture dislocation. In the remaining 190 fractures, included in 3 studies under review, no reported fracture classification was available. However, all 3 studies included patients with 4-part or 3-part fractures or fracture dislocation with articular head-split fractures.

Surgical approach and implant type

The deltopectoral approach was the most commonly used approach reported in 4 of the 7 studies reviewed in 180 patients (57.3%), The superolateral approach was used in 41 patients (13.1%) reported in the study by Gallinet et al.[24] The anterosuperior approach was used in 41 patients (13.1%). A study by Grubhofer et al[30] did not report the approach used in 51 patients (16.2%) included in the study (Table II).

The Aequalis reverse prosthesis (Tornier SAS, Montbonnot, France)[25,37] was used in 170 shoulders (44.5%), and of these, 87 patients (22.83%) had the Aequalis reverse fracture stem by Garofalo et al.[27] The Zimmer anatomical shoulder reversed prosthesis (Zimmer, Warsaw, IN, USA)[24] was implanted in 82 (21.5%) shoulders. The Delta III reverse shoulder prosthesis (DePuy Orthopedics, Warsaw, IN, USA)[9,13,24] was inserted in 71 shoulders (18.6%), the SMR Modular Shoulder System (Lima-LTO, San Daniele del Friuli, Italy)[8,9,46,62]

Table I Demography-related characteristics of studies evaluating outcomes of reverse shoulder arthroplasty in proximal humeral fractures in elderly patients

Study (yr)	Study design	Country	Age	Sex	F/U	Total patients	Lost to F/U	Analyzed
			Mean (range), yr	F/M	Mean (range) or ± SD, mo	(No.)	(No.)	(No.)
Cuff[19] (2013)*	Prospective nonrandomized comparative study	Italy	74.8 (70-86)	16/11	30 (24-48)	27	3	24
Sebastiá-Forcada[53] (2014)*	Randomized controlled trial	Spain	74.7 (70-85)	27/4	29.4 (24-44)	31	0	31
Gallinet[24] (2013)	Retrospective case control	France	76.9 (68-93)	27/14	24 (13-64)	53	12	41
Garofalo[27] (2015)	Retrospective cohort study	Italy	76.2 (61-90)	62/25	27 (24-32)	103	16	87
Grubhofer[30] (2016)	Retrospective multicenter cohort study	Switzerland	77 (58-89)	45/6	35 (12-90)	73	22	51
Chun[14] (2017)	Retrospective case control multicenter study	Republic of Korea	HT 81.1 (75-89) NHT 79.6 (73-87)	HT 12/2 NH 21/3	HT 36.5 ± 8.6 NHT 37.3 ± 9.3	47	9	38 (HT-14 NHT-24)
Torrens[59] (2018)	Retrospective cohort study	Spain	77.9 (62-90)	31/10	29 (24-37)	47	6	41
Weighted mean			76.83		29.84			

F/U, follow-up; *F*, female; *M*, male; SD, standard deviation; *HT*, healed tuberosity group; *NHT*, non healed tuberosity group.
* Indicates study with comparison between reverse shoulder and hemiarthroplasty.

was used in 31 shoulders (8.1%), and the DJO reverse shoulder prosthesis (DJO Surgical, Austin, TX, USA)[19] was applied in 27 shoulders (7.1%; Table II).

A total of 259 RSAs (82.5%) were cemented. The remaining 31 RSAs (9.9%) were implanted without cement. Intraoperative cement use was not reported in 24 patients. None of the studies specified use of antibiotic-loaded cement during implantation.

Tuberosity healing

All studies included for review described the technique for reattachment of the tuberosity and assessment of healing on radiologic assessment. All studies reported a similar tuberosity reattachment technique, specifically involving 2 horizontal and 2 vertical suture configurations. The suture materials used differed among the studies, however. Two studies, by Cuff et al[19] and Garofalo et al,[27] mentioned the use of bone graft to aid tuberosity healing. Although none of the studies specifically analyzed the effect of technique on tuberosity healing, the methods of tuberosity repair were comparable in HT and NHT groups.

For the purposes of this review, the term "tuberosity healing" refers to healing of the greater tuberosity. Most studies under review have described HT as healing of the greater tuberosity in an anatomic position. The series by Gallinet et al[24] compared 2 groups, where 1 group had tuberosity repair and in the other group tuberosity was excised, with 66% healing rate in the repair group. The weighted mean tuberosity healing rate was 70.58% (210 shoulders, Table II). The highest healing was reported by Grubhofer et al[30] and the lowest by Chun et al.[14] Nonunion or resorption of the tuberosity was seen in 104 shoulders (31.7% ± 15.9%).

Outcome assessment

Clinical and functional outcomes were evaluated based on healing of tuberosity after surgery and reported in 2 groups for comparison of HT and NHT groups.

ROM assessment

The outcomes were measured in terms of active ROM of the operated-on shoulder (Table III). Among studies under review, 6 studies[14,19,24,27,30,53] reported ROM as outcome measures in 273 shoulders (86.9%) comparing the 2 groups. The HT group showed significantly improved active forward flexion compared with the NHT group reported in 6 studies[14,19,24,27,30,53]

Table II Surgery-related characteristics of studies evaluating outcomes of reverse shoulder arthroplasty in proximal humeral fractures in elderly

Study (yr)	Fracture type (No. of patients)	Interval* Range or mean ± SD, d	Approach	Implant type†	Healed tuberosity (%)	Cemented/ cementless
Cuff[19] (2013)	NR	NR	Deltopectoral	DJO reverse prosthesis	83	NR
Sebastiá-Forcada[53] (2014)	3- part (5) 4-part (21) Dislocation (5)	5.1 (1-12)	Deltopectoral	SMR Lima prosthesis	64.5	Cementless
Gallinet[24] (2013)	3-/4-part	12 (2-70)	Superolateral	Delta III DePuy (24) Aequalis Tornier (20) Zimmer Anatomical reverse (9)	66	Cemented
Garofalo[27] (2015)	NR	3-15	Deltopectoral	Aequalis Tornier	75	Cemented
Grubhofer[30] (2016)	3-part (4) 4-part (38) HS (10)	5 (0-16)	NR	Zimmer Anatomical reverse	84.6	Cemented
Chun[14] (2017)	NR	HT 2.1 ± 1.6 NHT 1.9 ± 1.9	Deltopectoral	Aequalis Tornier	37	Cemented
Torrens[59] (2018)	3-part (7) 4-part (34)	11.6 (0-20)	Anterosuperior	Delta Xtend DePuy	68	Cemented
Weighted mean					70.58	

SD, standard deviation; *NR*, not reported; *HS*, head split; *H*, healed tuberosity group; *NHT* non-healed tuberosity group.

* Indicated interval between injury and surgery.

† Indicated number of patients in parenthesis. DJO reverse prosthesis, DJO Surgical, Austin, TX, USA; SMR, Modular Shoulder System, Lima-LTO, San Daniele del Friuli, Italy; Delta III, DePuy Orthopaedics, Warsaw, IN, USA; Aequalis, Tornier SAS, Montbonnot, France; Zimmer anatomical shoulder reversed prostheses, Zimmer, Warsaw, IN, USA.

(Table IV, Fig. 2), with weighted mean of 134° and 112° ($P < .05$), respectively (WMD, 21.71; 95% confidence interval [CI], 0.148-1.347). Similarly, shoulder abduction showed significantly better outcome in the HT group than in the NHT group, with weighted mean of 115° and 95° ($P < .05$) respectively, (WMD, 19.62; 95% CI, 0.103-0.906; Table V, Fig. 3). However, abduction was reported in 3 studies[24,30,53] only.

External rotation with elbow by the side was reported in 6 studies.[14,19,24,27,30,53] Of these, 5 studies[14,19,24,27,30] reported it in degrees, with the HT group showing significantly improved external rotation compared with the NHT group, with a weighted mean value of 28° and 8°, respectively (WMD, 20.18; 95% CI, 1.107-1.930; $P < .001$; Table VI, Fig. 4). One study[53] reported it in point system, with no significant difference between the 2 groups (1.9 and 2.5, respectively; $P = .184$). External rotation in 90° abduction was reported in 2 studies,[14,24] with a significantly higher range in the HT group compared with the NHT group ($P < .05$).

Internal rotation reporting was variable in different studies, with 2 studies[14,27] reporting it in degrees, with average of 30° ± 21° and 21° ± 6° in the HT and NHT group, respectively, and 2 studies[30,53] reporting it in a point system with a mean of 4 ± 2 and 3 ± 0.4, respectively. Internal rotation in 90° abduction was reported in 1 study[24] with significant difference between HT and NHT group at 55° and 37°, respectively ($P < .05$).

Functional scores

Functional scores were evaluated using the CMS, ASES, DASH, SSV, and SST scores (Table VII). The CMS was predominantly reported in 5 studies[14,24,30,53,59] under review. The weighted mean CMS was significantly better in the HT group than in the NHT group, with a score of 63.54 and 56.60, respectively (WMD, 6.94; 95% CI, 0.176-1.036; $P < .05$; Table VIII, Fig. 5). Only 2 studies[14,19] reported the ASES score, which was better in the HT group (76.15 ± 2.6) than in the NHT group (72.85 ± 3), but without significant difference. DASH[24] (30.1 and 39.3) VAS[14] (1.4 and 1.6), and SST[19] (7.7% and 7.1%) scores were reported only by 1 study each, with no significant difference between the 2 groups. SSV was measured in 1 study,[30] with a significant difference between the HT and NHT group (86 and 68, respectively).

Scapular notching

Scapular notching was reported in 82 patients (26.1%). Inferior scapular notching was identified using the Sirveaux classification.[57] According to the grading system, grade 1

Table III Comparison of range of motion between healed and non-healed tuberosity groups after Reverse shoulder arthroplasty for fracture proximal humerus

Range of motion	Study (yr)	Healed tuberosity, ° Mean (range) or ± SD	Nonhealed tuberosity, ° Mean (range) or ± SD	*P* value
Forward flexion	Cuff[19] (2013)	147 (126-172)	132 (102-150)	.213
	Sebastiá-Forcada[53] (2014)	112.1	117.5	.695
	Gallinet[24] (2013)	127.2	96.5	.002
	Garofalo[27] (2015)	145.3 ± 19.3	114.1 ± 15.8	<.001
	Grubhofer[30] (2016)	123 (45-165)	94 (40-130)	.01
	Chun[14] (2017)	125 ± 18	127 ± 14	.647
Abduction	Sebastiá-Forcada[53] (2014)	116.3	107.5	.399
	Gallinet[24] (2013)	112.8	90.4	.011
	Grubhofer[30] (2016)	115 (40-165)	92 (40-140)	.11
External rotation with elbow by side	Cuff[19] (2013)	28 (8-40)	12 (10-12)	.02
	Sebastiá-Forcada[53] (2014)	1.9*	2.5*	.184
	Gallinet[24] (2013)	19.7	1.6	.0004
	Garofalo[27] (2015)	34.3 ± 11.8	12.9 ± 11.6	<.001
	Grubhofer[30] (2016)	21 (10-60)	2 (0-10)	.01
	Chun[14] (2017)	29 ± 8	10 ± 9	<.001
External rotation in 90° abduction	Gallinet[24] (2013)	49.4	10.3	.00001
	Chun[14] (2017)	25 ± 10	7 ± 9	<.001
Internal rotation	Cuff[19] (2013)	50%	25%	.714
	Sebastiá-Forcada[53] (2014)	3.1*	2.4*	.157
	Gallinet[24] (2013)	Lumbar 4	Coccyx	.043
	Garofalo[27] (2015)	45.6 ± 18.9	25.7 ± 19.1	<.001
	Grubhofer[30] (2016)	6 (0-10)*	3 (0-8)*	.01
	Chun[14] (2017)	15 ± 2	17 ± 1	.125
Internal rotation in 90° abduction	Gallinet[24] (2013)	55.6	36.8	.004

* Indicates range of motion based on points system as part of the Constant-Murley score.

Table IV Comparison of forward flexion between healed and nonhealed tuberosity group after reverse shoulder arthroplasty for proximal humeral fractures

Study (yr)	Healed tuberosity			Nonhealed tuberosity			Total	WMD	SMD	SE	95% CI	Weight (%)
	Mean	SD	Total	Mean	SD	Total						Random
Cuff[19] (2013)	147	21.35	20	132	21.35	4	24	15	0.678	0.538	−0.437 to 1.794	13.10
Gallinet[24] (2013)	127.2	29.46	18	96.5	29.46	23	41	30.7	1.022	0.329	0.357-1.687	17.61
Sebastiá-Forcada[53] (2014)	122.1	30.95	20	117.5	30.95	11	31	4.6	0.145	0.366	−0.604 to 0.893	16.78
Garofalo[27] (2015)	145.3	19.3	66	114.1	15.8	21	87	31.2	1.668	0.279	1.114-2.222	18.69
Grubhofer[30] (2016)	123	28.18	44	94	28.18	8	52	29	1.014	0.391	0.227-1.800	16.22
Chun[14] (2017)	125	18	14	127	14	24	38	2	−0.126	0.330	−0.794 to 0.543	17.59
Total (random effects)	134.19*		182	112.48*		91	273	21.71*	0.747	0.305	0.148-1.347	100.00

WMD, weighted mean difference; *SMD*, standardized mean difference; *SE*, standard error; *CI*, confidence interval; *SD*, standard deviation.
Heterogeneity: $Q = 21.5975$, $df\ 5$, $P = .0006$, I^2 (inconsistency) = 76.85% (95% CI, 48.33%-89.63%).
* Weighted mean, $P < .001$, $t = 0.015$.

notching was seen in 41 patients (13.1%), grade 2 in 24 (7.6%), grade 3 in 5 (1.6%), and grade 4 in 12 (3.82%).

Complications

Complications were reported in all of the studies reviewed. There were 7 cases of deep infection,[24,27,30,53] where all underwent revision surgery. Nerve injury was reported in 8 patients, consisting of 1 radial nerve,[27] 1 ulnar nerve,[19] and 6 transient arm paresthesiae[59] that recovered in the postoperative period. There were 2 cases each of dislocation[24,59] and periprosthetic fracture[19,30] and hematoma[30,53] postoperatively. One case of superficial infection[27] and 1 case of lymphedema[24] were reported. Finally, 1 study[53] reported 5 shoulders with heterotopic ossification.

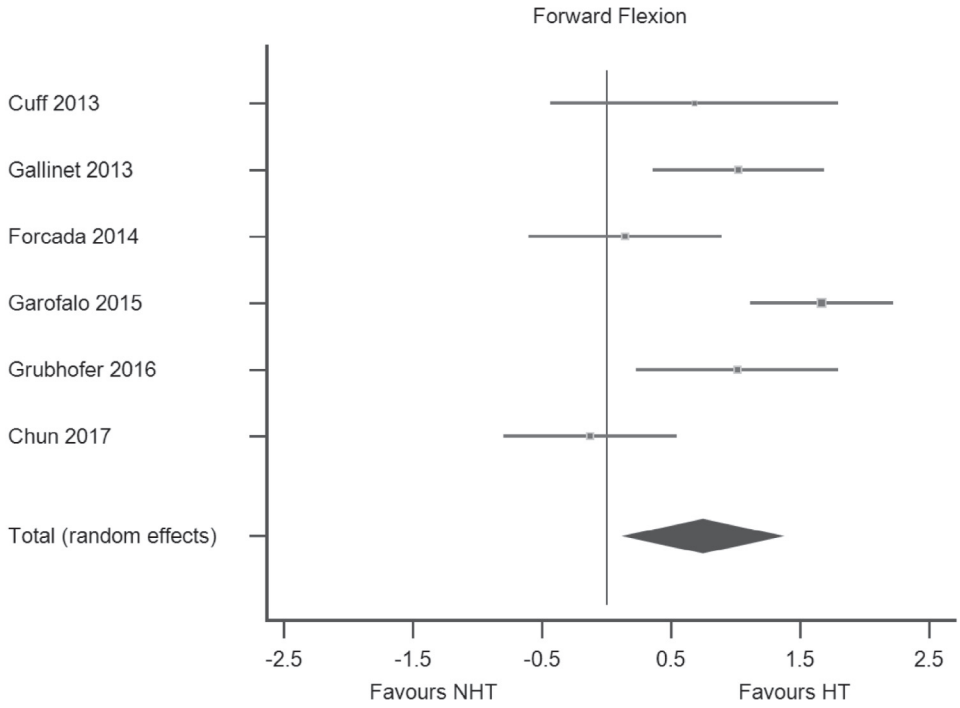

Figure 2 Comparison of forward flexion between healed tuberosity (*HT*) and nonhealed tuberosity (*NHT*) groups after reverse shoulder arthroplasty in controlled studies. The *solid squares* denotes the mean difference, the *diamond* denotes the weighted mean difference, and the *horizontal lines* represent the 95% confidence intervals.

Table V Comparison of abduction between healed and nonhealed tuberosity group after reverse shoulder arthroplasty for proximal humeral fractures

Study (yr)	Healed tuberosity			Nonhealed tuberosity			Total	WMD	SMD	SE	95% CI	Weight (%)
	Mean	SD	Total	Mean	SD	Total						Random
Gallinet[24] (2013)	112.8	38.58	18	90.4	38.58	23	41	32.4	0.569	0.315	−0.0677 to 1.206	17.61
Sebastiá-Forcada[53] (2014)	116.3	27.39	20	107.5	27.39	11	31	8.8	0.313	0.368	−0.439 to 1.065	16.78
Grubhofer[30] (2016)	115	36.78	44	92	36.78	8	52	23	0.616	0.383	−0.154 to 1.386	16.22
Total (random effects)	114.8*		82	95.18*		42	124	19.62*	0.504	0.203	0.103-0.906	100.00

WMD, weighted mean difference; *SMD*, standardized mean difference; *SE*, standard error; *CI*, confidence interval; *SD*, standard deviation.
Heterogeneity: $Q = 0.3984$, df 2, $P = .8194$, I^2 (inconsistency) 0.00% (95% CI, 0.0%- 83.16%).
* Weighted mean $P = .014$, $t = 2.485$.

Discussion

Complex proximal humeral fractures in the elderly pose several challenges in view of poor bone quality and difficult postoperative care due to impaired physiological or mental status,[34] tuberosity comminution, or a technical failure.[6,8,57] Recently, RSA has become increasingly popular as a treatment of choice for complex proximal humeral fractures, especially in the elderly.[41] RSA has the potential advantage of functional results being less dependent on tuberosity healing and rotator cuff integrity,[9] and the tuberosities have actually been excised in some published series.[13,35] These benefits remain uncertain, particularly in the context of a high rate of scapular notching and compromised external and internal rotation that are imperative for activities of daily living and thereby patient satisfaction.[13,25,51] The active rotational ROM and thus functional outcome may be improved with an attempt to achieve better tuberosity consolidation around stem and anatomic healing of tuberosity. Few recent studies have shown improved shoulder ROM and strength with healed tuberosity in RSA.[7,13] Our systematic review found that HT in RSA provided better ROM, especially external rotation and functional outcomes, compared with the NHT group.

In this systematic review, we observed that RSA was used in elderly patients with the mean age of 77.63 ± 2.14 years (range, 74-81 years). The patient population predominantly involved women, which comprised 81.7% of the total patients included in review. This reflects normal fracture

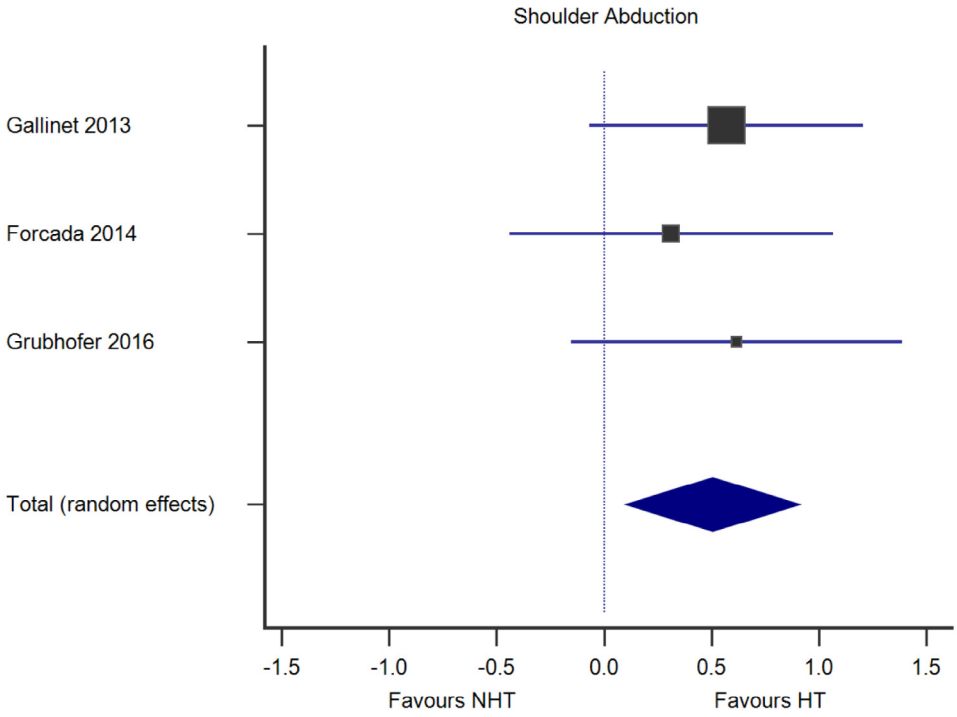

Figure 3 Comparison of abduction between healed tuberosity (*HT*) and nonhealed tuberosity (*NHT*) groups after reverse shoulder arthroplasty in controlled studies. The *solid squares* denote the mean difference, the *diamond* denotes the weighted mean difference, and the *horizontal lines* represent the 95% confidence intervals.

Table VI Comparison of external rotation between healed and nonhealed tuberosity group after reverse shoulder arthroplasty for proximal humeral fractures

Study	Healed tuberosity			Nonhealed tuberosity			Total	WMD	SMD	SE	95% CI	Weight (%)
	Mean	SD	Total	Mean	SD	Total						Random
Cuff[19] (2013)	28	11.65	20	12	11.65	4	24	16	1.326	0.562	0.160-2.492	11.18
Gallinet[24] (2013)	19.7	14.56	18	1.6	14.56	23	41	18.1	1.194	0.336	0.516-1.873	23.39
Garofalo[27] (2015)	34.3	11.8	66	12.9	11.6	21	87	21.4	1.805	0.284	1.241-2.368	28.28
Grubhofer[30] (2016)	21	18.46	44	2	18.46	8	52	19	1.014	0.391	0.228-1.800	19.21
Chun[14] (2017)	29	8	14	10	9	24	38	19	2.150	0.411	1.316-2.984	17.94
Total (random effects)	27.82*		162	7.64*		80	242	20.18*	1.518	0.209	1.107-1.930	100.00

WMD, weighted mean difference; *SMD*, standardized mean difference; *SE*, standard error; *CI*, confidence interval; *SD*, standard deviation.
Heterogeneity: $Q = 6.0803$, $df\ 4$, $P = .1932$, I^2 (inconsistency) 34.21% (95% CI, 00.00%-75.20%).
* Weighted mean $P < .001$, $t = 7.273$.

epidemiology.[11] The average follow-up after the surgery reported in the reviewed studies was 31 ± 4.7 months. Only 3 studies[30,53,59] reported fracture type based on the Neer classification, where the 4-part fracture pattern was most frequent, confirming this as being the most common indication for RSA in these reports.

Anatomic tuberosity healing has been considered an important factor that might result in better ROM and functional outcomes after RSA for proximal humeral fractures. Numerous studies report tuberosity healing rates after RSA for fracture, ranging from 47% to 100%.[4,9,19,24,28,39,53] This difference in healing rates may be attributed to fixation techniques and the type of prosthesis used. The overall average tuberosity healing rate was 68.3% ± 15.9% in all patients reported in studies reviewed. Recent efforts to enhance tuberosity healing after RSA in complex fractures include suture techniques and construct[23]; implant design with use of fracture-specific humeral stems, with large ingrowth surface for tuberosity healing[36,40]; bone graft and techniques[39]; and partial cementation techniques.[38,45]

ROM as an outcome measure was reported variably in studies under review. The weighted mean forward flexion and external rotation showed significant improvement in patients with tuberosity healing (Table IV). Of the 6 studies reporting forward flexion and external rotation, 3 studies found significant difference between 2 groups, whereas 3 other studies reported no significant difference in forward flexion and 5 studies reported significantly improved external

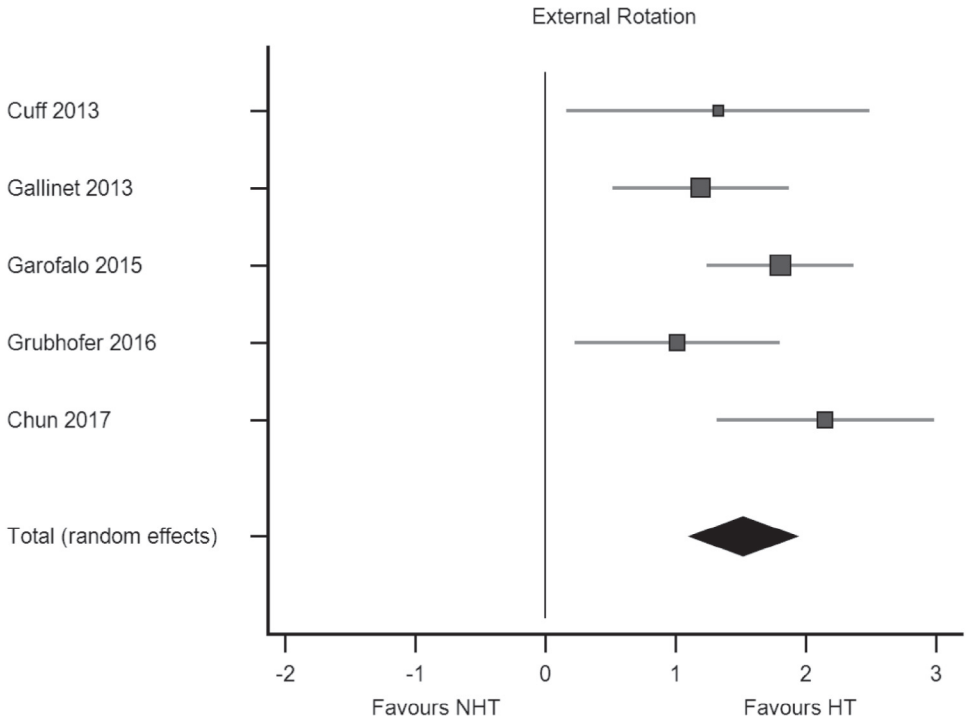

Figure 4 Comparison of external rotation between healed tuberosity (*HT*) and nonhealed tuberosity (*NHT*) groups after reverse shoulder arthroplasty in controlled studies. The *solid squares* denote the mean difference, the *diamond* denotes the weighted mean difference, and the *horizontal lines* represent the 95% confidence intervals.

Table VII Comparison of functional scores between healed and nonhealed tuberosity groups after reverse shoulder arthroplasty for proximal humeral fracture

Functional scores	Study (yr)	Healed tuberosity (mean)	Nonhealed tuberosity (mean)	*P* value
CMS	Sebastiá-Forcada[53] (2014)	59.3	53.9	.183
	Gallinet[24] (2013)	65.3	50.1	.0005
	Grubhofer[30] (2016)	65	50	.01
	Chun[14] (2017)	67.9 ± 11.6	63.9 ± 8.2	.228
	Torrens[59] (2018)	61 ± 9.5	61 ± 11.3	.91
ASES score	Chun[14] (2017)	74.3 ± 10.7	70.7 ± 7.2	.231
	Cuff[19] (2013)	78 (70-82)	75 (74-80)	.344
DASH	Gallinet[24] (2013)	30.1	39.3	.14
VAS for pain	Chun[14] (2017)	1.4 ± 1.4	1.6 ± 1.4	.647
SSV (%)	Grubhofer[30] (2016)	86	68	.03
SST	Cuff[19] (2013)	7.7 (6-9)	7.1 (6-9)	.385

CMS, Constant-Murley score; *ASES*, American Shoulder and Elbow Surgeons; *DASH*, Disability of Arm, Shoulder and Hand; *VAS*, visual analog scale; *SSV*, Subjective Shoulder Value; *SST*, Simple Shoulder Test.
Data are presented as mean ± standard deviation, mean (range), or as a single value.

rotation in the HT group. These results indicate a definite positive effect of tuberosity healing in achieving better external rotation and thus better function after RSA for proximal humeral fractures.

Similar outcomes were reported by Anakwenze et al[1] in systematic review that evaluated and compared ROM outcomes from studies that repaired the greater tuberosity and showed significantly better forward flexion and external rotation than studies in which the tuberosity was not repaired. However, this review compared a different subset of patient studies with tuberosity repair and those studies without and not including 2 comparable groups within same study. Bufquin et al[9] also found that active external rotation was greater when the greater tuberosity healed anatomically, although the difference was not significant. Grassi et al[29] presented their series and concluded that healing of the tuberosity made no difference in outcomes of RSA for proximal humeral fractures without subscapularis repair.

Functional outcomes, predominantly the CMS, reported in 5 studies showed a significantly better weighted mean

Table VIII Comparison of the Constant-Murley score between healed and nonhealed tuberosity groups after reverse shoulder arthroplasty for proximal humeral fractures

Study	Healed tuberosity			Nonhealed tuberosity			Total	WMD	SMD	SE	95% CI	Weight (%)
	Mean	SD	Total	Mean	SD	Total						Random
Gallinet[24] (2013)	65.3	12.73	18	50.1	12.73	23	41	15.2	1.171	0.335	0.494-1.848	20.98
Sebastiá-Forcada[53] (2014)	59.3	10.54	20	53.9	10.54	11	31	5.4	0.499	0.371	−0.260 to 1.258	18.84
Grubhofer[30] (2016)	65	14.57	44	50	14.57	8	52	15	1.014	0.391	0.228 to 1.800	17.75
Chun[14] (2017)	67.9	11.6	14	63.9	8.2	24	38	4	0.409	0.333	−0.265 to 1.084	21.10
Torrens[59] (2018)	61	9.5	28	61	11.3	13	41	0	0.000	0.329	−0.666 to 0.666	21.32
Total (random effects)	63.54*		124	56.6*		79	203	6.94*	0.606	0.218	0.176 -1.036	100.00

WMD, weighted mean difference; *SMD*, standardized mean difference; *SE*, standard error; *CI*, confidence interval; *SD*, standard deviation.
Heterogeneity: $Q = 7.7558$, $df\ 4$, $P = .1009$, I^2 (inconsistency) = 48.43% (95% CI, 00.00%-81.10%).
* Weighted mean $P = .006$, $t = 2.777$.

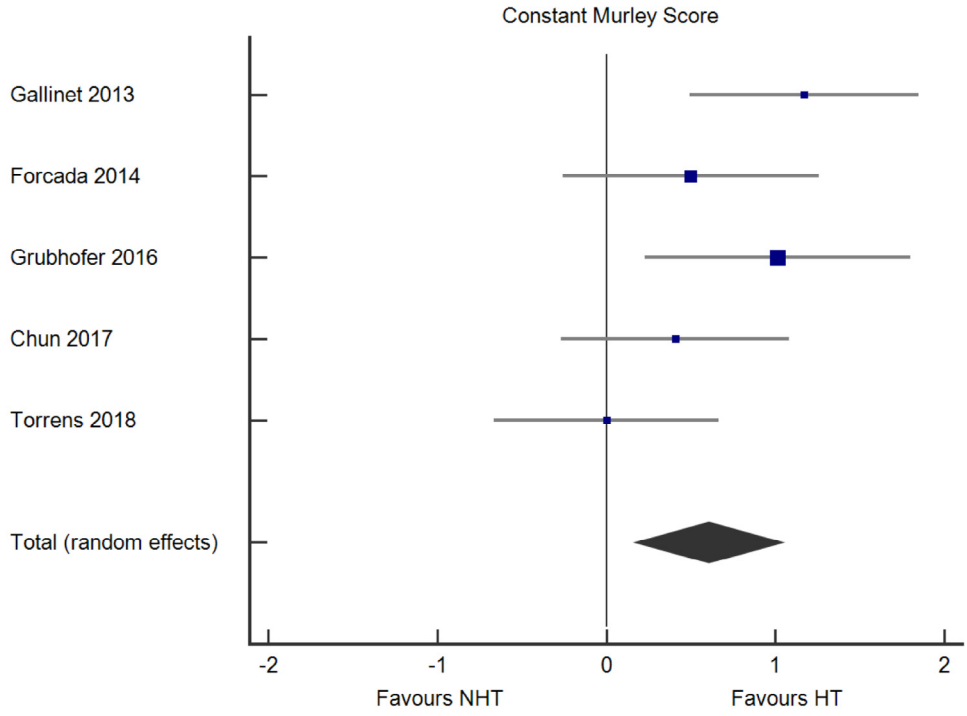

Figure 5 Comparison of Constant-Murley Score between healed tuberosity (*HT*) and nonhealed tuberosity (*NHT*) groups after reverse shoulder arthroplasty in controlled studies. The *solid squares* denote the mean difference, the *diamond* denotes the weighted mean difference, and the *horizontal lines* represent 95% confidence intervals.

score in patients with tuberosity healing. Gallinet et al[24] and Grubhofer et al[30] reported significant difference in the CMS, whereas Sebastiá-Forcada et al[53] and Chun et al[14] reported better scores with no statistical significant difference among the 2 study groups, and Torrens et al[59] showed no difference between the two groups. Thus, there are conflicting results in reporting the CMS as an outcome measure. The ASES score was reported by 2 studies,[14,19] which showed a better score in HT group, with no significant difference.

Klein et al[35] used the juxta-articular approach without acromial osteotomy, removing tuberosities without reattaching the rotator cuff, and Cazeneuve et al[13] used the anterolateral approach without reattaching the tuberosity. However, both displayed predictable and comparable results in functional outcomes.

Scapular notching has been reported as a form of complication in the review. This affected 26.1% of total patients included in the review. In RSA, incidence of scapular notching varies widely from 19% to 96%.[54,55] However long-term follow-up is needed to evaluate the effect of scapular notching because it reveals itself at approximately the first year after implantation, its incidence rises with duration of follow-up, and there is paucity of data on the effect of

notching on clinical and functional outcomes. In the absence of a significant clinical event, whether scapular notching should be considered a complication or just a radiographic finding in RSA remains a matter of debate. Other complications reported were superficial infection, deep infection, hematoma formation, periprosthetic fractures, dislocations, and nerve injury. There was no uniformity in reporting complications among the studies under review.

Some limitations of the study should be noted. Firstly, the study is limited by the quality of the primary studies reviewed.

Secondly, only 1 randomized controlled trial was included. But in this study, randomization was done between HA and RSA and not HT and NHT groups as evaluated in present review study.

Thirdly, most of the studies included in the review are presented by one specialist shoulder team, and the results and the outcomes of these studies may not be reproducible or more widely generalizable.

Fourthly, different implant designs from various manufacturers were used in the studies under review. Most studies used standard configuration reverse prostheses; however, Garofalo et al[27] used a dedicated fracture stem and 4-mm lateralized glenosphere to reduce the risk of scapular notching. The result evaluated based on tuberosity healing showed significantly better outcomes in the HT group. Implant design may have an influence over outcomes, particularly ROM, but this is beyond the scope of this review.

Fifthly, outcomes such as abduction were reported in only 3 of 7 studies included in the review. Functional scores, such as ASES, were reported in only 2 studies, and DASH, VAS, SST, and SSV scores were reported only by 1 study each. Consequently, there were limitations in using these criteria for assessment of outcomes.

Sixthly, we included only 7 studies reporting 381 patients. This may not be fully representative of the population with these fractures.

Finally, the limitation to the English language may have missed some of the other potentially relevant literature. Inclusion of only published studies might have introduced publication bias.

Conclusion

In the context of increasing use of RSA for complex proximal humeral fractures in older patients, RSA with HT seems to result in better functional outcomes compared with RSA with NHT. However, due to the absence of good-quality studies, uncertainty still exists whether tuberosity fixation will improve outcomes with RSA. Further studies are needed in the form of rigorous randomized controlled trials with specific evaluation of outcomes based on greater tuberosity healing with RSA for complex proximal humeral fractures.

Disclaimer

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Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jse.2018.09.006.

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