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A systematic review of tuberosity healing and outcomes following reverse shoulder arthroplasty for fracture according to humeral inclination of the prosthesis

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Background: Proximal humerus fractures are common in the elderly population and are often treated with reverse shoulder arthroplasty (RSA). The purpose of this systematic review was to compare tuberosity healing and functional outcomes in patients undergoing RSA with humeral inclinations of 135°, 145°, and 155°.

Methods: A systematic review was performed of RSA for proximal humerus fracture using Preferred Reporting Items for Systemic Reviews and Meta-Analyses (PRISMA) guidelines. Radiographic and functional outcome data were extracted to evaluate tuberosity healing according to humeral inclination. Analysis was also performed of healed vs. nonhealed tuberosities.

Results: A total of 873 patients in 21 studies were included in the analysis. The mean age was 77.5 years (range of 58-97) and the mean follow-up was 26.2 months. Tuberosity healing was 83% in the 135° group compared with 69% in the 145° group and 66% in the 155° group ($P = .030$). Postoperative abduction was highest in the 155° group ($P < .001$). No significant difference was found in forward flexion, external rotation, or postoperative Constant score between groups. Patients with tuberosity healing demonstrated 18° higher forward flexion ($P = .008$) and 16° greater external rotation ($P < .001$) than those with unhealed tuberosities.

Conclusion: RSA for fracture with 135° humeral inclination is associated with higher tuberosity healing rates compared with 145° or 155°. Postoperative abduction is highest with a 155° implant, but there is no difference in in postoperative forward flexion, external rotation, or Constant score according to humeral inclination. Patients with healed tuberosities have superior postoperative forward flexion and external rotation than those with unhealed tuberosities.

Institutional review board approval was not required for this systematic review.

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Proximal humerus fractures account for 4%-6% of all fractures, representing the third most common location of fractures in patients older than 65 years after the hip and distal radius.[24] As the elderly population continues to increase, it is estimated that the incidence of proximal humerus fractures will triple in the next 30 years.[39]

Hemiarthroplasty (HA) was traditionally the surgical treatment of choice for complex 3- and 4-part proximal humerus fractures.[37] However, functional outcomes with hemiarthroplasty are largely dependent on tuberosity healing, which is very difficult to achieve.[3,40] Because reverse shoulder arthroplasty (RSA) is less dependent on tuberosity healing for maintenance of function and stability, it has become the preferred prosthetic treatment option for complex proximal humerus fractures in patients older than 65 years.[30,43] Multiple studies have demonstrated improved functional outcomes when using RSA compared with HA.[1,5,7,10,18,30,44] However, achieving tuberosity healing is desirable after RSA given that patients with tuberosity healing appear to have improved functional outcomes.[2,25]

Several factors may contribute to tuberosity healing following RSA for fracture, including repair technique, patient health, postoperative rehabilitation, and prosthesis design. Implant variables such as an inlay vs. onlay humeral cup, glenosphere offset, and humeral component neck-shaft angle all change the postoperative position of the tuberosities and consequent tension on the tuberosity repair.[20] A reduction in tension, such as through a more anatomic neck-shaft angle, may lead to improvement in tuberosity healing. However, little comparative information is available to compare outcomes based on these factors. In particular, the influence of humeral inclination on tuberosity healing has not been well defined.

The purpose of this systematic review was to compare tuberosity healing and functional outcomes in patients undergoing RSA with humeral inclinations of 135°, 145°, and 155°. The hypothesis was that tuberosity healing would be higher using an RSA prosthesis with a humeral inclination of 135° compared with 155°, and that postoperative external rotation would be higher with a 135° prosthesis.

Methods

This systematic review was officially registered with PROSPERO on September 18, 2019. Medical and scientific literature included in PubMed (MEDLINE) and Cochrane library databases were searched in accordance with Preferred Reporting Items for Systemic Reviews and Meta-Analyses (PRISMA) guidelines. The search strategy was employed using the following algorithm: ''(reverse shoulder arthroplasty OR reverse total shoulder OR reverse shoulder prosthesis) AND proximal humerus fracture.'' The search was limited to publications in the English language consisting of Level I to IV evidence[38] published on or prior to the day of registration. This was supplemented by manual review of included reference lists to include studies not otherwise identified.

Inclusion criteria included information about the prothesis used (for categorization of humeral inclination angle), tuberosity healing, a mean patient age of at least 65 years, and a minimum follow-up of 6 months. Case reports, review articles, conference papers, cadaveric studies, animal studies, and Level V evidence studies were excluded. The initial search provided 288 studies. After duplicates were removed, abstracts were reviewed and screened for eligibility. Seventy-three full-text articles were subsequently assessed for inclusion and exclusion criteria (Fig. 1).

The literature review was conducted by 1 author (J.O.). Studies that met inclusion criteria were reviewed in full by 2 authors for final inclusion (J.O. and P.J.D.). Articles in question were discussed between authors to determine eligibility. Epidemiologic, surgical, radiologic, and clinical data were extracted from the selected articles in a systematic approach. Risk of bias was carefully evaluated for each study during extraction. Study design, patient demographics, follow-up, surgical approach, prosthetic used, and tuberosity healing rate were extracted from all studies. If available, data related to functional assessment including range of motion and patient-reported functional outcomes were included for analysis.

All statistical analysis was performed by a trained statistician. Dichotomous data are reported as proportion and 95% confidence interval (CI). Continuous data are presented as mean ± standard deviation; when not provided, standard deviation was calculated from *t*-test *P* value (if available). Review Manager (RevMan5) software (The Cochrane Collaboration, London, UK) was used to generate pooled fixed and random effects estimates using inverse variance weighting. Heterogeneity was assessed using *Q* statistic. We performed subgroup analysis to identify any differences by angle. Statistical significance was set at $P < .05$.

Results

A total of 21 studies were included in the final analysis. These consisted of 10 Level III studies,[2,7,8,15,17,26,36,47-49] 9 Level IV studies,[6,13,21,22,35,41,46,53,54] 1 Level II study,[10] and 1 Level I study.[44] Six studies were prospective,[6,10,13,35,44,53] 14 were retrospective,[2,7,8,15,17,21,22,26,36,46-49,54] and 1 included a cohort with both prospective and retrospective patients.[41] There were 11 studies that exclusively used a 155° inclination prosthesis,[2,6,8,15,17,21,22,36,41,47,48] 4 with a 145° inclination prosthesis,[7,26,46,53] and 5 with a 135°

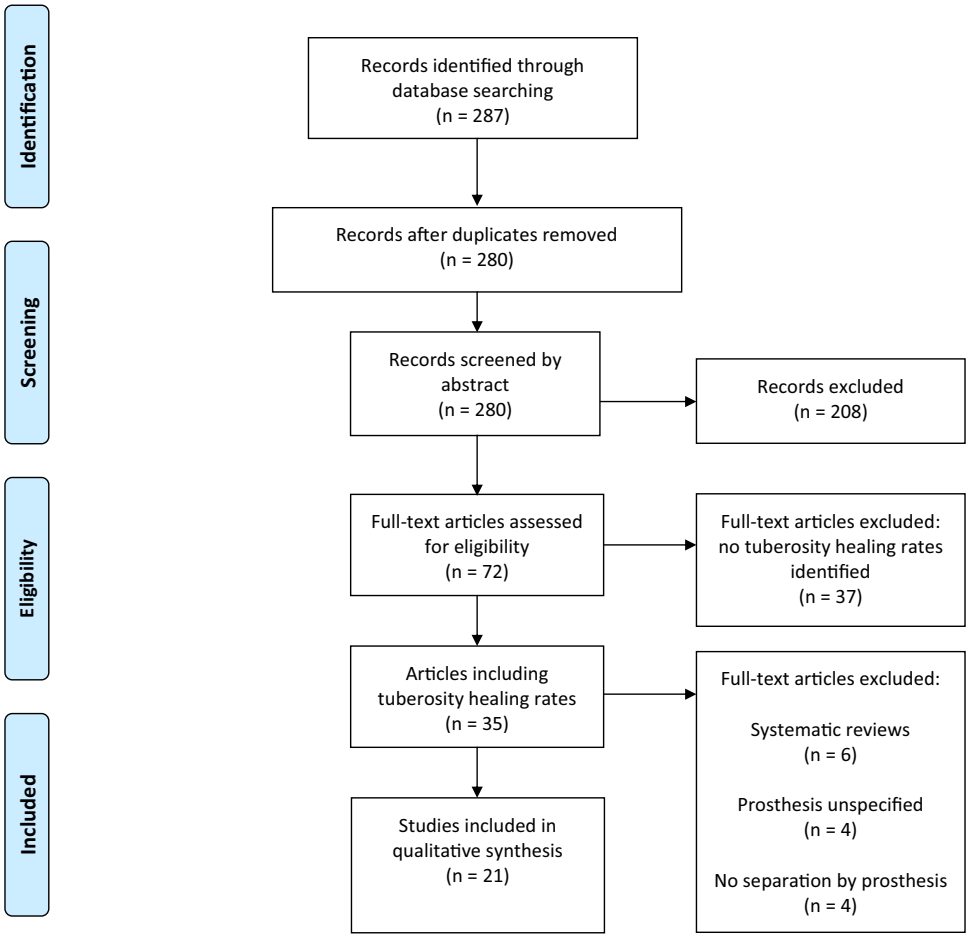

Figure 1 Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow diagram representing study inclusion process.

inclination prosthesis.[10,13,35,44,54] One study[49] investigated both 145° and 155° humeral inclinations and was subsequently treated as 2 separate studies for the purposes of statistical analysis. All studies were published between 2007-2019. Three studies[7,10,44] compared an RSA cohort to other treatment modalities, including hemiarthroplasty and open reduction internal fixation. Garofalo et al[17] was the largest study, involving a total of 87 patients, whereas Levy and Badman[35] had the smallest cohort, including 7 patients.

Demographics

There were a total of 873 patients from all 21 studies. Seventy-five were lost to follow-up, leaving 798 patients with a mean age of 77.3 years (range 58-97) that were evaluated at a mean of 27.6 months postoperatively. The majority (75%) were women. The studies and demographics are summarized in Table I.

Surgical technique

Five hundred ninety-five patients (68%) received a 155° humeral inclination prosthesis, 168 patients (19%) received a 145° inclination, and 110 patients (13%) received a 135° inclination. A deltopectoral approach was used in 627 patients (72%), and a lateral approach was used in 173 patients (20%). Gallinet et al[15] did not report their approach. Cement was used in 644 patients (74%). Two studies did not report the use of cement in their surgical methods (Table II).[10,22]

Tuberosity healing

Tuberosity healing was reported in each study, with a total of 781 patients analyzed radiographically for evidence of greater tuberosity healing (Fig. 2). The overall rate of tuberosity healing was 71% (95% CI 64%, 77%). Tuberosity healing was 83% in the 135° group compared with 69% in the 145° group and 66% in the 155° group ($P = .030$; Table III). Chun et al[8] and Reuther et al[41] (both 155° inclination) reported the lowest proportion of tuberosity healing at 37% and 46%, respectively.

Functional outcome

All 21 studies reported forward flexion in their results. Standard deviation was not reported or reproducible in 6

Table I Demographic information of studies included in the systematic review

Angle	Study, yr	Level of evidence	Total patients		Age, yr		Sex, F/M
			Baseline	Analyzed	Mean	Range	
135°	Cuff (2013)[10]	Level II	27	24	74.8	70-86	16/11
	Formaini (2015)[13]	Level IV	25	25	77	63-88	17/8
	Levy (2011)[35]	Level IV	7	7	86	78-91	5/2
	Sebastia-Forcada (2014)[44]	Level I	31	31	74.7	70-85	27/4
	Youn (2016)[54]	Level IV	20	20	76.5	62-87	18/2
145°	Chalmers (2014)[7]	Level III	9	9	77	NR	7/9
	Jorge-Mora 2019)[26]	Level III	58	58	77	NR	55/3
	Simovitch (2019)[46]	Level IV	55	55	77	65-87	38/17
	Verdano (2018)*[,49]	Level III	32	32	77.4	67-92	24/8
	Wright (2019)[53]	Level IV	30	30	71	NR	26/4
155°	Boileau (2019)[2]	Level III	38	38	80	70-88	33/4
	Bufquin (2007)[6]	Level IV	43	40	78	65-97	41/2
	Chun (2017)[8]	Level III	47	38	80.4	73-89	33/5
	Gallinet (2013)[15]	Level III	53	41	77	68-93	38/3
	Garofalo (2015)[17]	Level III	103	87	76	61-90	62/25
	Grassi (2014)[21]	Level IV	19	15	75	70-83	15/0
	Grubhofer (2016)[22]	Level IV	73	51	77	58-89	45/6
	Lopiz (2016)[36]	Level III	42	42	82	76-88	34/8
	Reuther (2019)[41]	Level IV	81	81	79	59-91	72/9
	Torrens (2018)[47]	Level III	47	41	78	62-90	31/10
	Uzer (2017)[48]	Level III	33	33	73.2	65-82	21/12
	Verdano (2018)*[,49]	Level III					

NR, not reported; *F*, female; *M*, male.
* Study including both 145° and 155° humeral inclinations.

studies and were therefore excluded from the meta-analysis.[6,15,36,44,49,54] One study reported forward flexion only based on Constant-Murley point score and was also excluded in the final review.[47] Seven studies in the 155° group,[2,8,17,21,22,41,48] 4 studies in the 145° group,[7,26,46,53] and 3 studies in the 135° group[10,13,35] were included for analysis (Fig. 3). The overall mean postoperative forward flexion was 124° (95% CI 118°, 130°). No significant difference was noted between groups, with weighted mean postoperative flexion of 126° in the 155° group, compared with 123° in the 145° group and 125° in the 135° group ($P = .960$; Table III).

Abduction was recorded in 9 studies in the 155° group, 3 studies in the 145° group, and 3 studies in the 135° group. Five studies had an unavailable standard deviation and were excluded from the review.[6,15,36,44,49] Two studies reported abduction only based on Constant-Murley point score and were excluded.[21,47] Three studies in the 155° group,[22,41,48] 2 studies in the 145° group,[26,46] and 2 studies in the 135° group[13,35] were included for analysis (Fig. 4). The overall mean postoperative abduction was 100° (95% CI 88°, 111°). The 155° group demonstrated the highest postoperative abduction with a weighted mean of 108°, compared with 105° in the 145° group and 83° in the 135° group ($P < .001$; Table III).

External rotation with elbow by the side was recorded in all of the studies. Six studies had an unavailable standard deviation and were excluded from the review.[2,6,7,15,36,49] Three studies reported external rotation only based on Constant-Murley point score and were excluded.[21,44,47] Five studies in the 155° group,[8,17,22,41,48] 3 studies in the 145° group,[26,46,53] and 3 studies in the 135° group[10,13,35] were included for analysis (Fig. 5). Overall mean postoperative external rotation was 26° (95% CI 21°, 30°). No significant difference was noted between the 155° (24°), 145° (29°), and 135° groups (25°) ($P = .300$; Table III).

Internal rotation was recorded in 11 studies in the 155° group, 5 studies in the 145° group, and 3 studies in the 135° group. A total of 7 studies reported internal rotation only based on Constant-Murley point score.[2,13,21,22,46,47,53] Additionally, 3 studies qualitatively assessed internal rotation,[15,36,49] and 1 study reported internal rotation as a percentage.[10] Because of the wide variety of inputs and lack of uniformity, internal rotation was not included in this meta-analysis.

The Constant score was the most widely used outcome score and was subsequently further analyzed; the score was reported in 11 studies in the 155° group, 3 studies in the 145° group, and 2 studies in the 135° group. Five studies did not include standard deviation and were excluded.[6,15,22,44,49]

Table II Operative data of studies included in the systematic review

Angle	Study, yr	Follow-up, mo		Approach[†]	Prosthetic[†,‡]	Cemented[†]
		Mean	Range			
135°	Cuff (2013)[10]	30	24-48	Deltopectoral	DJO Reverse	NR
	Formaini (2015)[13]	17	NR	Deltopectoral	DJO Monoblock	Cemented
	Levy (2011)[35]	12	12-23	Deltopectoral	DJO Reverse	Cemented
	Sebastia-Forcada (2014)[44]	28.5	24-49	Deltopectoral	Lima SMR	Uncemented
	Youn (2016)[54]	36	30-93.6	Deltopectoral	Lima SMR	Uncemented
145°	Chalmers (2014)[7]	14.4	NR	Deltopectoral	Zimmer TM	Cemented
	Jorge-Mora (2019)[26]	26	6-56	Deltopectoral (54) Superolateral (4)	FH Ortho Arrow (24) Fx Solutions Humelock II (34)	Cemented (24) Uncemented (34)
	Simovitch (2019)[46]	33.7	24-62	Deltopectoral	Exactech Equinoxe	Cemented (53) Uncemented (2)
	Verdano (2018)*[,49]	14.3	NR	Deltopectoral	Exactech Equinoxe	Cemented (10)
	Wright (2019)[53]	32	12-95	Deltopectoral	Zimmer TM	Uncemented
155°	Boileau (2019)[2]	36	24-59	Superior transdeltoid (34) Deltopectoral (4)	Aequalis Tornier	Cemented
	Bufquin (2007)[6]	22	6-58	Superolateral (20) Deltopectoral (23)	DePuy Delta	Cemented
	Chun (2017)[8]	37	NR	Deltopectoral	Aequalis Tornier	Cemented
	Gallinet (2013)[15]	24	13-61	Superolateral transdeltoid	DePuy Delta CTA (24) Aequalis Tornier (20) Zimmer RA (9)	Cemented
	Garofalo (2015)[17]	27	24-32	Deltopectoral	Aequalis Tornier	Cemented
	Grassi (2014)[21]	22	12-46	Deltopectoral	DePuy Delta Xtend	Cemented
	Grubhofer (2016)[22]	35	12-90	NR	Zimmer RA	NR
155°	Lopiz (2016)[36]	32.6	NR	Deltopectoral	DePuy Delta Xtend	Cemented
	Reuther (2019)[41]	24.8	12-76.8	Deltopectoral (66) Deltoid-splitting (15)	Mathys Affinis	Cemented
	Torrens (2018)[47]	29	24-37	Anterosuperior	DePuy Delta Xtend	Cemented
	Uzer (2017)[48]	16.7	12-25	Deltopectoral	DePuy Delta Xtend	Cemented
	Verdano (2018)*[,49]	14.3	NR	Deltopectoral	Zimmer Bigliani-Flatow	Cemented (10)

NR, not reported.

* Study included patients with both 145° and 155° humeral inclinations.

† Number of patients indicated in parentheses.

‡ DJO Reverse and DJO Monoblock, DJO Surgical, Austin, TX, USA; Lima SMR, Lima Corporate, San Daniele del Friuli, Italy; Zimmer TM, Zimmer RA, and Zimmer Bigliani-Flatow, Zimmer, Warsaw, IN, USA; FH Ortho Arrow, FH Ortho, Chicago, IL, USA; Fx Solutions Humelock II, Fx Solutions, Viriat, France; Exactech Equinoxe; Exactech Inc, Gainesville, FL, USA; Aequalis Tornier, Tornier, Edina, MN, USA; DePuy Delta, DePuy Delta CTA, and DePuy Delta Xtend, DePuy Orthopaedics, Warsaw, IN, USA; Mathys Affinis, Mathys Ltd Bettlach, Bettlach, Switzerland.

Seven studies in the 155° group,[2,8,21,36,41,47,48] 2 studies in the 145° group,[26,46] and 1 study in the 135° group[54] were included for analysis (Fig. 6). The overall mean postoperative Constant score was 57 (95% CI 53, 61). There was no difference in postoperative Constant score between groups ($P = .300$; Table III).

Healed vs. unhealed tuberosities

Patients from all studies were pooled to investigate postoperative range of motion differences in healed compared with unhealed tuberosities. Fourteen studies provided forward flexion data in patients with healed and unhealed tuberosities. Three studies in the 135° group,[10,13,35] 4 studies in the 145° group,[7,26,46,53] and 7 studies in the 155° group[2,8,17,21,22,41,48] were included for analysis. The healed group demonstrated 18° higher of postoperative forward flexion compared with the unhealed group (95% CI 5°, 32°; $P = .008$). No difference was detected in forward flexion when comparing healed and unhealed tuberosities between humeral inclination subgroups ($P = .890$).

Seven studies provided abduction data in patients with healed and unhealed tuberosities, including 2 studies in the 135° group,[13,35] 2 studies in the 145° group,[26,46] and 3 studies in the 155° group.[22,41,48] There was no statistically significant difference in postoperative abduction based on tuberosity healing either overall (95% CI −12°, 42°; $P = .280$) or between humeral inclination subgroups ($P = .640$).

Eleven studies reported external rotation data in patients with healed and unhealed tuberosities, including 3 studies

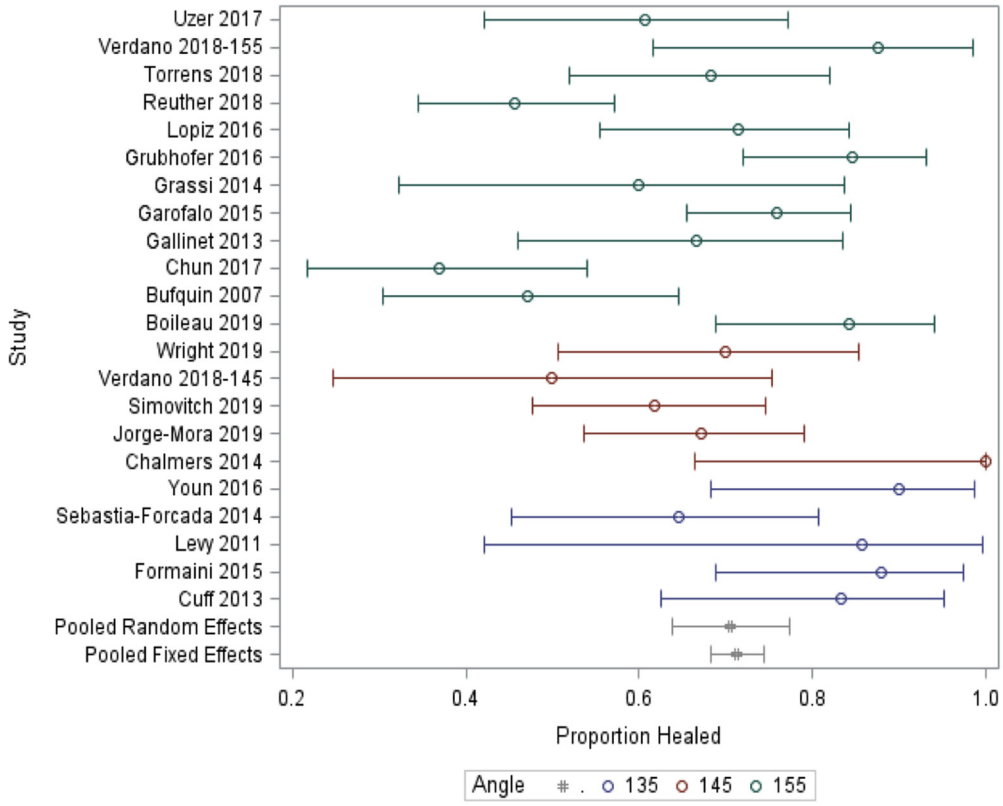

Figure 2 Comparison of tuberosity healing in patients undergoing RSA for fracture with humeral inclinations of 135°, 145°, and 155°. The *circles* indicate the mean difference and the *horizontal lines* represent the 95% confidence intervals. *RSA*, reverse shoulder arthroplasty.

Table III Comparison of postoperative outcomes in patients undergoing RSA for fracture with humeral inclinations of 135°, 145°, and 155°

Outcome	Total, pooled random effects (95% CI)	135° inclination, pooled random effects (95% CI)	145° inclination, pooled random effects (95% CI)	155° inclination, pooled random effects (95% CI)	*P* value
Tuberosity healing, %	71 (64, 77)	83 (74, 92)	69 (57, 82)	66 (57, 76)	.030*
Range of motion, degrees					
Forward flexion	124 (118, 130)	125 (109, 141)	123 (105, 140)	126 (119, 133)	.960
Abduction	100 (88, 111)	83 (78, 89)	105 (95, 116)	108 (89, 126)	.0003*
External rotation	26 (21, 30)	25 (21, 29)	29 (18, 40)	24 (17, 31)	.300
Functional scores					
CMS	57 (53, 61)	54 (49, 59)	61 (54, 67)	55 (50, 61)	.300

RSA, reverse shoulder arthroplasty; *CI*, confidence interval; *CMS*, Constant-Murley score.
* Statistical significance ($P < .05$).

in the 135° group,[10,13,35] 3 studies in the 145° group,[26,46,53] and 5 studies in the 155° group.[8,17,22,41,48] Patients with healed tuberosities demonstrated 16° greater postoperative external rotation than those with unhealed tuberosities (95% CI 11°, 20°; $P < .001$). No difference was detected in external rotation between humeral inclination subgroups ($P = .880$).

Discussion

The primary finding of this study is that humeral inclination appears to affect tuberosity healing following RSA for proximal humerus fracture. Tuberosity healing was 83% with the use of a 135° prosthesis compared with 69% with a 145° prosthesis and 66% with a 155° prosthesis. This

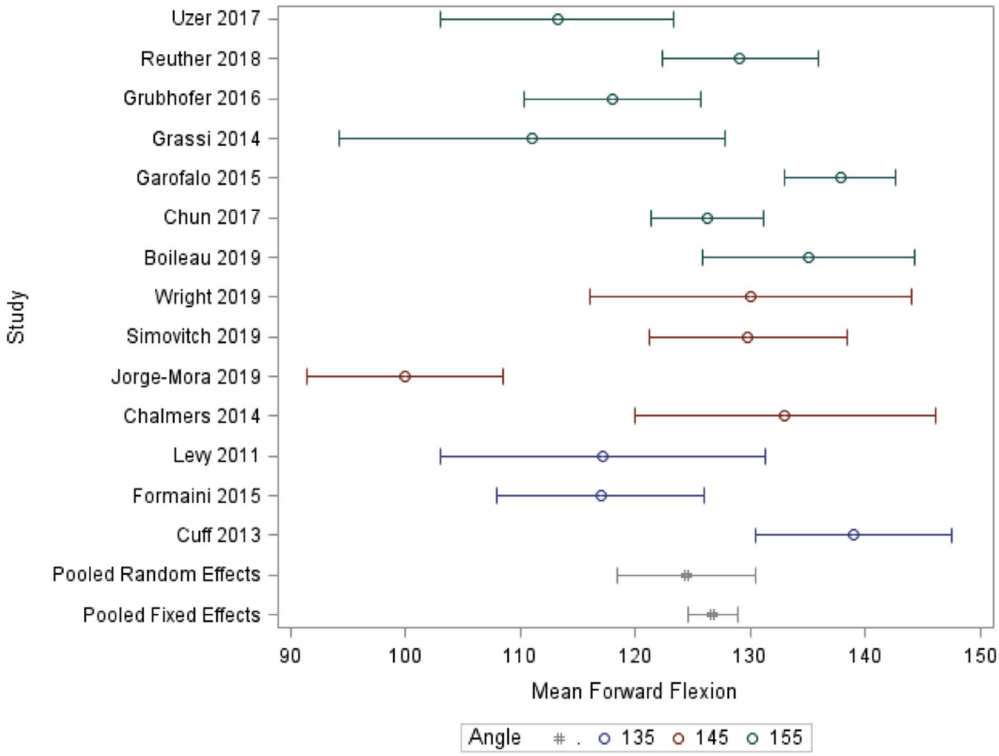

Figure 3 Comparison of forward flexion in patients undergoing RSA for fracture with humeral inclinations of 135°, 145°, and 155°. The *circles* indicate the mean difference and the *horizontal lines* represent the 95% confidence intervals. *RSA*, reverse shoulder arthroplasty.

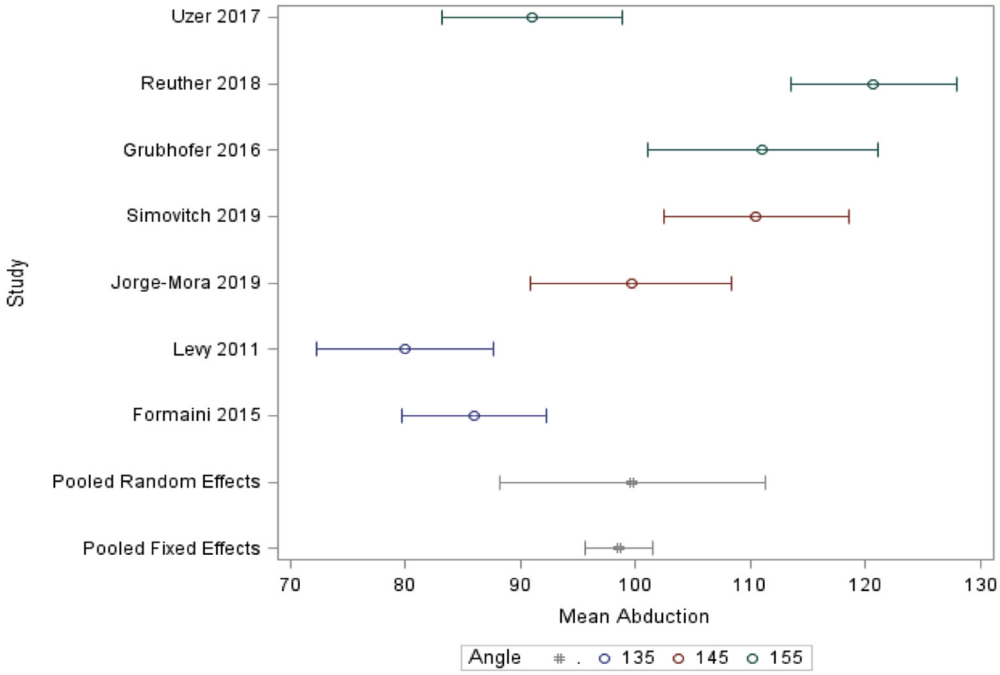

Figure 4 Comparison of abduction in patients undergoing RSA for fracture with humeral inclinations of 135°, 145°, and 155°. The *circles* indicate the mean difference and the *horizontal lines* represent the 95% confidence intervals. *RSA*, reverse shoulder arthroplasty.

finding confirmed the first portion of the hypothesis. However, contrary to the study hypothesis, there was no difference in postoperative external rotation based on humeral inclination. The only difference in postoperative range of motion between groups was abduction, which was highest with a 155° inclination.

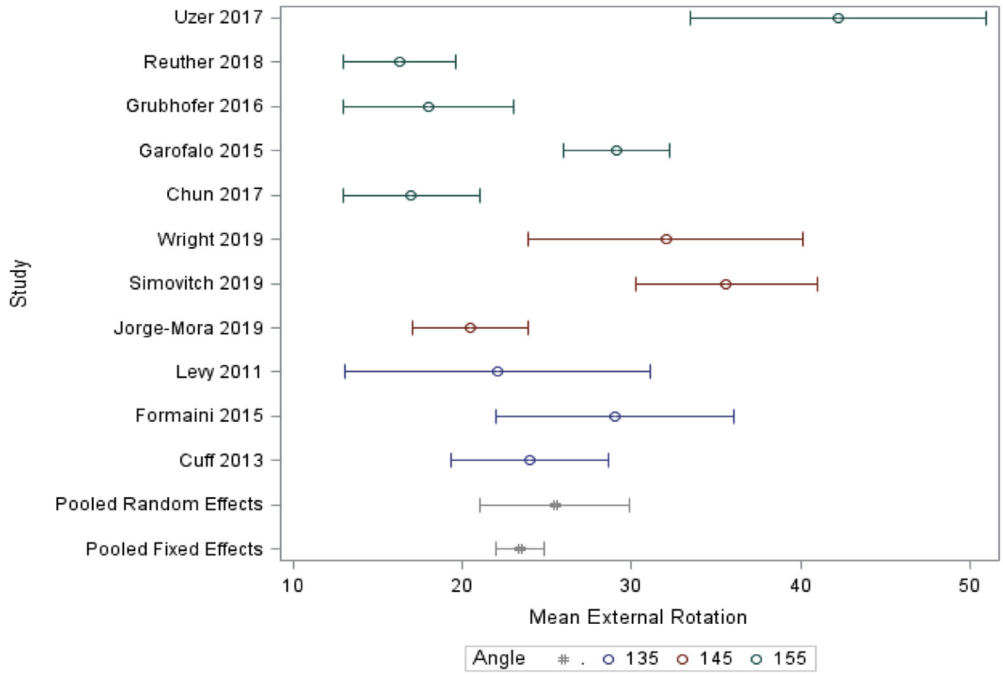

Figure 5 Comparison of external rotation in patients undergoing RSA for fracture with humeral inclinations of 135°, 145°, and 155°. The *circles* indicate the mean difference and the *horizontal lines* represent the 95% confidence intervals. *RSA*, reverse shoulder arthroplasty.

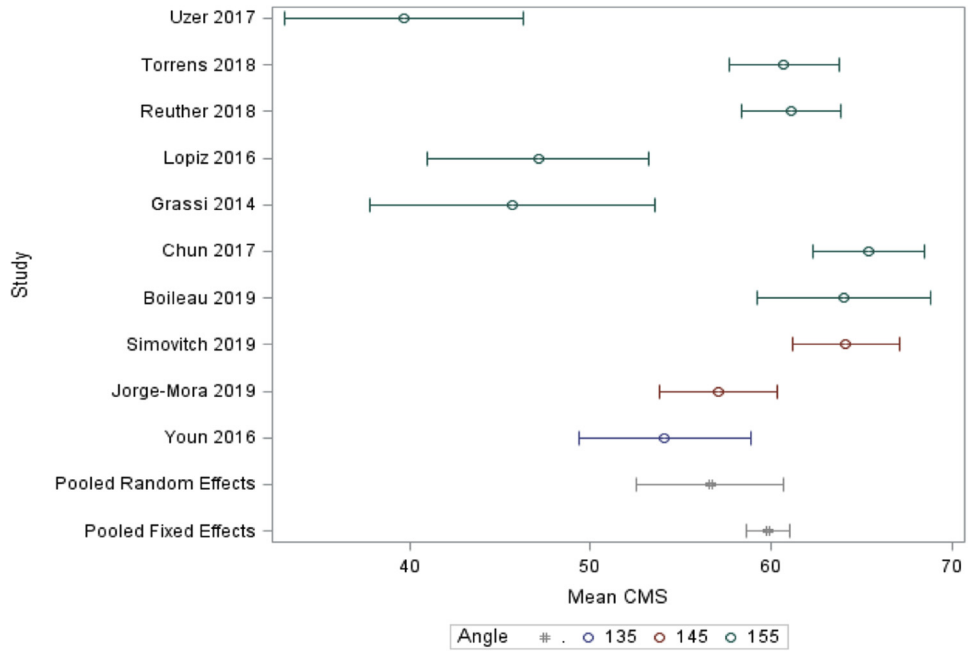

Figure 6 Comparison of Constant score in patients undergoing RSA for fracture with humeral inclinations of 135°, 145°, and 155°. The *circles* indicate the mean difference and the *horizontal lines* represent the 95% confidence intervals. *RSA*, reverse shoulder arthroplasty.

Management of proximal humerus fractures in the elderly is challenging because of a porous bone structure, compromised vascularity, comorbid health conditions, and pre-existing limitations in movement capacity. In hemiarthroplasty, functional outcomes are highly associated with anatomic tuberosity healing.[4] Unfortunately, tuberosity healing following hemiarthroplasty is unreliable, with failure contributed from poor prosthetic positioning, poor position of the greater tuberosity, and women older than 75 years.[3] These factors have made RSA more appealing than hemiarthroplasty.[30]

In this review, the overall rate of tuberosity healing with RSA was 71%. Shukla et al[45] performed a systematic review investigating the treatment of proximal humerus fractures and found a similar tuberosity healing rate of 76% after RSA. However, they did not evaluate healing according to humeral inclination. In the current study, tuberosity healing was highest with the use of a 135° prothesis (83% vs. 66%-69%; $P = .030$). This is likely because the 135° humeral inclination most closely restores the native center of rotation and thus leads to less tension on the repair postoperatively. Assuming proper prosthesis positioning in terms of height, the 135° will lead to less distalization of the tuberosities postoperatively.[31,32]

Tuberosity repair technique likely affects healing. For instance, biomechanical work in an RSA model, as well as clinical reports from hemiarthroplasty, have reported that cerclage fixation can improve healing compared with suture to prosthesis fixation.[11,14,28] Tuberosity repair technique in the studies evaluated in this review was often poorly described and highly variable. Interestingly, tuberosity healing rates were particularly varied in the 155° inclination group, ranging from 37%-88%. Chun et al[8] hypothesized that their 37% rate of healing was due to the prosthesis characteristics, tuberosity fixation methods, and older patient population. Some authors reported the use of autografts in their fixation technique. Uzer et al[48] found that tuberosity healing was improved when an autograft was used (78%) compared with no autograft (47%) while using a 155° inclination. Similarly, Levy and Badman[35] found a high rate of tuberosity healing (88%) using a horseshoe graft with a 135° inclination, which potentially provided biologic support to the healing. Further work needs to be done to optimize repair techniques of the tuberosities following RSA for fracture.

In addition to affecting tuberosity healing, humeral inclination of the prosthesis may affect postoperative range of motion.[12] In a computer simulation model, Gutierrez et al[23] reported that increasing the humeral neck-shaft angle from 130° to 150° was associated with improved impingement-free abduction (although adduction was limited by a more horizontal angle). In additional, computer-simulated models comparing various humeral inclinations, both Lädermann et al[31] and Werner et al[52] found a similar reduction in abduction from lowering the humeral neck-shaft angle due to bony impingement superiorly. In the current study, abduction was highest in the 155° groups, similar to the findings of these simulation models. Because abduction is largely a function of the deltoid, it is logical that this movement would not depend on tuberosity healing and be strictly related to bony impingement.

In contrast to abduction, no significant differences were noted between the 135°, 145°, and 155° humeral inclinations for forward flexion ($P = .960$) or external rotation ($P = .300$). In computer modeling, Lädermann et al[33] reported that a 135° model significantly improved adduction, extension, and external rotation compared with the 145° or 155° models. Related biomechanical studies have provided additional confirmation that decreasing humeral neck-shaft angle to a more varus inclination resulted in significant increase in impingement-free range of motion.[27,52] However, contrary to computer-simulated models, our meta-analysis did not find superior external rotation or forward flexion with lower humeral inclinations in RSA. A variety of factors likely account for this discrepancy. First, there is the role of tuberosity healing. Second, prothesis position is likely more variable in a fracture situation. Third, soft tissue trauma may play a greater role in the fracture environment. Finally, this review did not account for variables such as glenosphere offset, inlay vs. onlay humeral design, or humeral component version, which may contribute to functional outcomes. Further study is needed to evaluate these variables.

Initially there was some question as to whether tuberosity repair was required for RSA for fracture. The evidence now appears to be clear that active range of motion is improved when the tuberosities heal. In the current review, patients with healed tuberosities were found to have improved forward flexion (18° higher; $P = .008$) and external rotation (16° greater; $P < .001$) than those with unhealed tuberosities. Another systematic review found that patients with tuberosity healing had a 22° increase in forward flexion, 20° increase in abduction, and 20° increase in external rotation compared with patients with nonhealed tuberosities.[25] Boileau et al[2] similarly found that patients with healed tuberosities following RSA for proximal humerus fracture demonstrated a 26° improvement in forward flexion and 16° improvement in external rotation compared with those with unhealed tuberosities. Furthermore, among patients with unhealed tuberosities, 66% had difficulties of activities of daily living requiring external rotation.

Proper external rotation has been determined to be of remarkable importance in activities of daily living including eating with a spoon, drinking from a glass, combing hair, and using a cell phone.[34] In examining the kinematic effects of tuberosity healing, Sabesan et al[42] found that an unhealed tuberosity resulted in a decrease in deltoid muscle activation, specifically during external rotation with the arm at side. Additionally, the authors reported decreased glenohumeral joint reaction forces during external rotation in the unhealed tuberosity group, which may lead to postoperative instability. Neurovascular injury following proximal humerus fracture poses a threat to recovery, with electromyographic evidence of axonal denervation occurring in up to 67% of patients.[50] Nerve lesions tend to recover well given stability of the shoulder during recovery.[51] Tuberosity healing following RSA provides additional joint stability, serving as an internal splint to ensure healing and prevent further neurologic insult.[19,29]

The overall mean postoperative Constant score was 57 (95% CI 53, 61), with no difference identified between the 135°, 145°, and 155° humeral inclinations. A recent study by Gallinet et al[16] investigating outcomes of 422 patients

undergoing RSA for proximal humerus fracture determined the same absolute Constant score of 57 and tuberosity healing rate of 71% among patients who underwent tuberosity repair. For reference, a Constant score of 57 is within range of individuals aged 91-100 years using a healthy population.[9] Therefore, these scores still represent a decline from normal for most individuals. However, tuberosity repair should still be the goal as patients in their study who underwent tuberosity excision had lower postoperative Constant scores compared with those who had repair (58 vs. 53; $P = .004$).

Together, these studies demonstrate that outcome after RSA for proximal humerus fracture can be optimized by achieving tuberosity healing. Thus, prostheses used for RSA for fracture should be designed to encourage healing. In addition to anatomic humeral inclination, other potential modifications may exist.

Limitations

This study has several limitations. The analysis is limited by the database search and literature review, which poses the risk of missed studies. Of the studies involved, the majority were of lower levels of evidence consisting primarily of retrospective reviews. There was 1 prospective, randomized controlled trial[44] as well as only 1 study investigating a direct comparison of 2 prosthetic inclinations.[49] The limitations of this study are subject to the inherent limitations of the included studies. Although the patient population was similar among studies, potential confounding variables such as pre-existing comorbidities, level of independence, and postoperative care were not assessed. Tuberosity repair method in particular varied and may influence healing. In addition, further variability besides humeral neck inclination exists between prosthesis, particularly glenoid lateralization and superior-inferior position. Further study is needed to evaluate how these factors affect tuberosity healing.

Conclusions

RSA for fracture with a 135° prothesis inclination is associated with higher tuberosity healing rates compared with 145° or 155°. Postoperative abduction is highest with a 155° implant, but there is no difference in postoperative forward flexion, external rotation, or Constant score according to humeral inclination. Patients with healed tuberosities have superior postoperative forward flexion and external rotation compared with those with unhealed tuberosities. Based on this information, we recommend a 135° prothesis inclination when RSA is used for fracture.

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