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Outcomes for type C proximal humerus fractures in the adult population: comparison of nonoperative treatment, locked plate fixation, and reverse shoulder arthroplasty

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Background: This study compares patient-reported outcomes and range of motion (ROM) between adults with an AO Foundation/Orthopaedic Trauma Association type C proximal humerus fracture managed nonoperatively, with open reduction and internal fixation (ORIF), and with reverse shoulder arthroplasty (RSA).

Methods: This is a retrospective cohort study of patients >60 years of age treated with nonoperative management, ORIF, or RSA for AO Foundation/Orthopaedic Trauma Association type 11C proximal humerus fractures from 2015 to 2018. Visual analog scale pain scores, Patient-Reported Outcomes Measurement Information System (PROMIS) scores, ROM values, and complication and reoperation rates were compared using analysis of variance for continuous variables and chi square analysis for categorical variables.

Results: A total of 88 patients were included: 41 nonoperative, 23 ORIF, and 24 RSA. At the 2-week follow-up, ORIF and RSA had lower visual analog scale scores and lower PROMIS pain interference scores ($P < .05$) than nonoperative treatment. At the 6-week follow-up, ORIF and RSA had lower visual analog scale, PROMIS pain interference, and PF scores and better ROM ($P < .05$) than nonoperative treatment. At the 3-month follow-up, ORIF and RSA had better ROM and PROMIS pain interference and PF scores ($P < .05$) than nonoperative treatment. At the 6-month follow-up, ORIF and RSA had better ROM and PROMIS PF scores ($P < .05$) than nonoperative treatment. There was a significantly higher complication rate in the ORIF group than in the non-operative and RSA groups ($P < .05$).

Conclusion: The management of AO Foundation/Orthopaedic Trauma Association type 11C proximal humerus fractures in older adults with RSA or ORIF led to early decreased pain and improved physical function and ROM compared to nonoperative management at the expense of a higher complication rate in the ORIF group.

Proximal humerus fractures are treated based on numerous factors, including patient age, fracture type, calcar comminution, osteoporosis, vascular status of the humeral head, rotator cuff function, surgeon expertise, and a patient's health and functional status.[10,16,27-29,33,51,52,54,56] AO Foundation/Orthopaedic Trauma Association (AO/OTA) type C proximal humerus fractures are challenging fractures to standardize treatment in the adult patient population because of age, complex fracture patterns, osteoporotic bone, high incidence of rotator cuff tears, and variable health and functional status.[9,14,23,32,33,38,49,53] As a result, there is a substantial amount of debate regarding the optimal treatment of AO/OTA type C proximal humerus fractures in the adult population.[31]

The mainstay treatments include nonoperative management, open reduction internal fixation (ORIF) with locked plating, hemiarthroplasty (HA), and reverse shoulder arthroplasty (RSA).[8,28] The majority of proximal humerus fractures is managed nonoperatively and has been associated with good outcomes for both nondisplaced and displaced fractures.[15,21,24,44] In contrast, some studies suggest nonoperative treatment results in slower return of function, less

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pain relief, and even higher mortality rate.[9,32] The literature also supports operative treatment for AO/OTA type C proximal humerus fractures.[1,3,7,11,13,17,30,34,37,40,48,50-52,55,56] ORIF has been a staple for surgical management of proximal humerus fractures throughout the years[24]; however, the use of RSA in the treatment for proximal humerus fractures has increased as experience with and outcomes of RSA have improved.[13,24,40,46,48,50,55,56] Recent studies have compared these surgical options in order to optimize outcomes and assist in surgical decision-making for complex proximal humerus fractures in the adult population.[11,53,57] However, there is a paucity of evidence directly comparing clinical and patient-reported outcomes (PROs) among nonoperative management, ORIF, and RSA. This information will be helpful to further understand outcomes, guide treatment, and counsel patients with AO/OTA type C proximal humerus fractures

The aim of this study was to compare early outcomes including range of motion (ROM), PROs, complications, and secondary operations of nonoperative management, ORIF with locked plating, or RSA for AO/OTA type C proximal humerus fractures in adult patients older than the age of 60 years.

Materials and methods

Patient population

Following institutional review board approval, patients with a closed proximal humerus fracture treated either nonoperatively, with ORIF, or with RSA at a single, large, tertiary referral center between January 2015 and December 2018 were retrospectively identified using Current Procedural Terminology codes 23600, 23615, and 23472. Definitive treatment was decided by the attending surgeon based on age, fracture morphology, medical comorbidities, activity level, and patient preference. All patients were treated by fellowship-trained orthopedic surgeons from a large academic practice who were experienced in treating proximal humerus fractures. The inclusion criterion was patients aged 60 years or older who sustained an AO/OTA type C (Neer 4-part) proximal humerus fracture as identified on initial injury radiographs and underwent definitive nonoperative management, ORIF with locked plating, or RSA within the first 4 weeks postinjury.[36] Patients were excluded if they were younger than 60 years at the time of injury, sustained an open or pathologic fracture, presented with multiple long bone fractures, and underwent percutaneous pinning, intramedullary nailing, and HA. Patients were also excluded if they did not have a minimum of 1 year of clinical and radiographic follow-up.

Data collection

Patient demographics and baseline characteristics were recorded including age, sex, body mass index, smoking status, and comorbidity burden. Of note, comorbidity burden was assessed using a modified Charlson comorbidity index with the age component excluded in order to evaluate age and comorbidity burden separately. ROM data, including active forward flexion (aFF), passive forward flexion (pFF), and external rotation (ER), were recorded at 2-week, 6-week, 3-month, 6-month, and 1-year clinical follow-up visits. ROM data were collected primarily from physical therapy notes to standardize measurements. PROs were also assessed at follow-up visits, including visual analog scale shoulder pain scores and Patient-Reported Outcomes Measurement Information System (PROMIS) pain interference, physical function, and depression domain scores.

Any complications that occurred up to 1 year after treatment were recorded. Complications included nonunion, avascular necrosis, intraarticular screw cutout, hardware failure, adhesive capsulitis, and periprosthetic fracture. The presence of scapular notching or tuberosity malunion/resorption on postoperative radiographs at any time point was recorded for RSA patients.

Nonunion was defined as a lack of union progression over 3 months or absence of complete union by 9 months.[2,42] Secondary operations within 1 year of treatment were also recorded including revision ORIF, conversion to arthroplasty, removal of hardware, and lysis of adhesions. Malunion was assessed on postoperative radiographs for the nonoperative and ORIF cohorts and defined as HSA $<120^\circ$ or $>150^\circ$, or head-shaft translation >5 mm.[47]

Statistical analysis

Statistical analysis was performed using Stata/SE 17.0 for Mac (StataCorp LP, College Station, TX, USA). Baseline patient characteristics were compared among nonoperative, ORIF, and RSA groups using 1-way analysis of variance or chi square analysis for continuous and categorical variables, respectively. Differences in ROM values and PRO scores at follow-up visits between treatment groups were assessed using 1-way analysis of variance. Ross et al[45] previously utilized a threshold of 90° of aFF to indicate satisfactory functional outcome for 3-part and 4-part proximal humerus fractures. This metric was used at the final follow-up to compare satisfactory functional outcomes among nonoperative, ORIF, and RSA cohorts utilizing chi square analysis. Associations between treatment type and malunion, complication, and secondary operation rates were determined using chi square analysis. Statistical significance was set at $P < .05$.

Results

A total of 149 patients with AO/OTA type 11C proximal humerus fractures were identified. Sixty-one patients were excluded from the study based on the following: pathologic fracture (n = 4), multiple long bone fractures (n = 10), previous shoulder surgery (n = 3), underwent HA (n = 5), inadequate clinical or radiographic follow-up (n = 39). A total of 88 patients were included in the study with the following: 41 were managed nonoperatively, 23 underwent ORIF, and 24 underwent RSA. Average clinical and radiographic follow-up for each one of the groups included 2.0 years for nonoperative, 1.8 years for ORIF, and 2.4 years for RSA ($P = .2$). On average, patients who underwent ORIF were younger than those managed nonoperatively or with RSA (ORIF = 67 years, nonoperative = 77 years, RSA = 77 years; $P < .01$). No other significant differences in patient characteristics were identified between groups ($P > .05$ for all, Table I).

Table II and Figure 1, *A–C* detail the ROM data for the nonoperative, ORIF, and RSA cohorts. At 2 weeks, patients among all 3 groups demonstrated 0° of aFF but had statistically significant differences in pFF (RSA = 47°, ORIF = 10°, nonoperative = 0°; $P < .01$) and ER (RSA = 3°, ORIF = 1°, nonoperative = 0°; $P < .01$), which reflects the early activity limitations ascribed for each treatment option. At 6 weeks, RSA patients had greater aFF (57° vs 34° vs 18°; $P < .01$), pFF (114° vs 58° vs 51°; $P < .01$), and ER (23° vs 15° vs 14°; $P = .04$) than ORIF and nonoperative patients. Similarly, at 3 months, the RSA cohort demonstrated significantly greater aFF (125° vs 85° vs 59°; $P < .01$) and pFF (138° vs 108° vs 70°; $P < .01$) than the ORIF and nonoperative cohorts. At 6 months, significantly greater aFF (RSA = 133°, ORIF = 106°, nonoperative = 93°; $P < .01$) and pFF (RSA = 148°, ORIF = 125°, nonoperative = 116°; $P < .01$) were observed for RSA patients, but ER was similar between groups ($P = .56$). At the final follow-up, achievement of a satisfactory functional outcome (aFF >90 degrees) was significantly higher in

Table I
Baseline characteristics

	Nonoperative (N = 41)	ORIF (N = 23)	RSA (N = 24)	*P* value*
Age (mean ± SD, yr)	77.4 ± 10.1	67.1 ± 5.5	77.3 ± 9.5	**<.01**
Sex (n)				.15
Female	90.2% (37)	78.3% (18)	95.8% (23)	
Male	9.8% (4)	21.7% (5)	4.2% (1)	
Body mass index (n)				.87
Nonobese (<30 kg/m^2)	57.5% (23)	63.6% (14)	62.5% (15)	
Obese (≥30 kg/m^2)	42.5% (17)	36.4% (8)	37.5% (9)	
Smoking status (n)				.80
Nonsmoker	95.1% (39)	91.3% (21)	91.7% (22)	
Smoker	4.9% (2)	8.7% (2)	8.3% (2)	
Ageless CCI (mean ± SD)	2.2 ± 2.0	1.4 ± 1.7	1.6 ± 1.8	.19

CCI, Charlson comorbidity index; *SD*, standard deviation; *ORIF*, open reduction internal fixation; *RSA*, reverse shoulder arthroplasty.
Boldface indicates statistical significance.
**P* values calculated using analysis of variance and chi square analysis for continuous and categorical variables, respectively.

Table II
Range of motion outcomes

	Nonoperative (N = 41)	ORIF (N = 23)	RSA (N = 24)	*P* value*
Active forward flexion (mean ± SD, °)				
2-week follow-up	0 ± 0	0 ± 0	0 ± 0	–
6-week follow-up	18.4 ± 29.2	34.1 ± 31.7	57.1 ± 50.8	**<.01**
3-month follow-up	58.9 ± 47.3	84.5 ± 37.9	125.1 ± 20.4	**<.01**
6-month follow-up	93.0 ± 31.2	105.6 ± 28.3	133.0 ± 22.5	**<.01**
Passive forward flexion (mean ± SD, °)				
2-week follow-up	0 ± 0	9.6 ± 27.6	46.5 ± 47.7	**<.01**
6-week follow-up	50.5 ± 41.4	58.3 ± 41.7	114.1 ± 31.5	**<.01**
3-month follow-up	70.0 ± 52.6	108.2 ± 37.9	137.5 ± 21.2	**<.01**
6-month follow-up	116.0 ± 23.1	125.4 ± 14.8	147.9 ± 15.1	**<.01**
External rotation (mean ± SD, °)				
2-week follow-up	0 ± 0	0.5 ± 1.5	3.3 ± 6.1	**<.01**
6-week follow-up	13.5 ± 15.1	14.7 ± 14.9	23.4 ± 13.8	**.04**
3-month follow-up	23.8 ± 24.0	30.8 ± 21.2	37.3 ± 21.3	.09
6-month follow-up	37.9 ± 20.5	38.1 ± 19.5	44.1 ± 19.4	.56

ORIF, open reduction internal fixation; *RSA*, reverse shoulder arthroplasty; *SD*, standard deviation.
Boldface indicates statistical significance.
**P* values calculated using analysis of variance.

the RSA (91.7%, n = 22) and ORIF (65.2%, n = 15) cohorts than in the nonoperative (31.7%, n = 13) cohort ($P < .01$).[45]

PROs were also compared among the groups (Table III and Fig. 2, *A–D*). Significant differences in visual analog scale pain scores were observed among the groups at 2 weeks (RSA = 2.7, ORIF = 2.4, nonoperative = 6.2; $P < .01$), 6 weeks (RSA = 1.1, ORIF = 2.1, nonoperative = 3.5; $P < .01$), and 1 year ($P < .01$) but not at 3 months ($P = .33$) or 6 months ($P = .24$). In addition, PROMIS pain interference scores were significantly different among the groups at 2 weeks (RSA = 63.8, ORIF = 64.1, nonoperative = 68.9; $P = .02$), 6 weeks (RSA = 57.4, ORIF = 57.3, nonoperative = 61.0; $P = .04$), and 3 months (RSA = 50.0, ORIF = 55.2, nonoperative = 59.6; $P < .01$) but not at 6 months ($P = .10$) or 1 year ($P = .07$). PROMIS physical function scores were significantly different among the groups at 6 weeks (RSA = 33.8, ORIF = 35.9, nonoperative = 30.7; $P < .01$), 3 months (RSA = 39.0, ORIF = 40.8, nonoperative = 35.4; $P = .045$), 6 months (RSA = 42.2, ORIF = 44.8, nonoperative = 37.4; $P = .01$), and 1 year (RSA = 46.0, ORIF = 48.1, nonoperative = 37.9; $P = .01$) but not at 2 weeks ($P = .23$). No differences in PROMIS depression scores were identified at any follow-up time point ($P > .05$ for all).

Malunion, complication, and secondary operation rates are described in Table IV. Nonoperative management was associated with a higher malunion rate than ORIF (77.5% vs 38.9%, $P < .01$). The complication rate was significantly higher in the ORIF group (nonoperative = 9.8%, ORIF = 34.8%, RSA = 4.2%; $P < .01$). Complications in the nonoperative group included nonunion (n = 1) and avascular necrosis (n = 3). Complications in the ORIF group included avascular necrosis (n = 3), hardware failure (n = 2), screw cutout (n = 1), and adhesive capsulitis (n = 2). Complications in the RSA group included a nondisplaced periprosthetic fracture (n = 1). Scapular notching was identified on 20% of RSA patients' postoperative radiographs (n = 5). ORIF patients also experienced a significantly higher rate of secondary operations (nonoperative = 4.9%, ORIF = 34.8%, RSA = 0.0%; $P < .01$). The most common secondary operation was conversion to RSA (nonoperative = 2, ORIF = 4). Other secondary operations for the ORIF group included revision fixation (n = 1), removal of hardware (n = 1), and lysis of adhesions (n = 2).

Discussion

The optimal treatment of AO/OTA proximal humerus fractures in the older adult population remains highly debated, with literature to support nonoperative management, ORIF, and RSA.[22,29,37-53] To our knowledge, the presented study is the first one to directly compare functional outcomes among nonoperative, ORIF, and RSA for the management of AO/OTA type C proximal humerus fractures in adult patients older than the age of 60 years. In our cohort, surgical treatment was associated with an early reduction in pain and improved physical function when compared to nonoperative management. Pain appears to normalize between groups by the 1-year follow-up visit; however, the improved physical function is sustained in the surgical

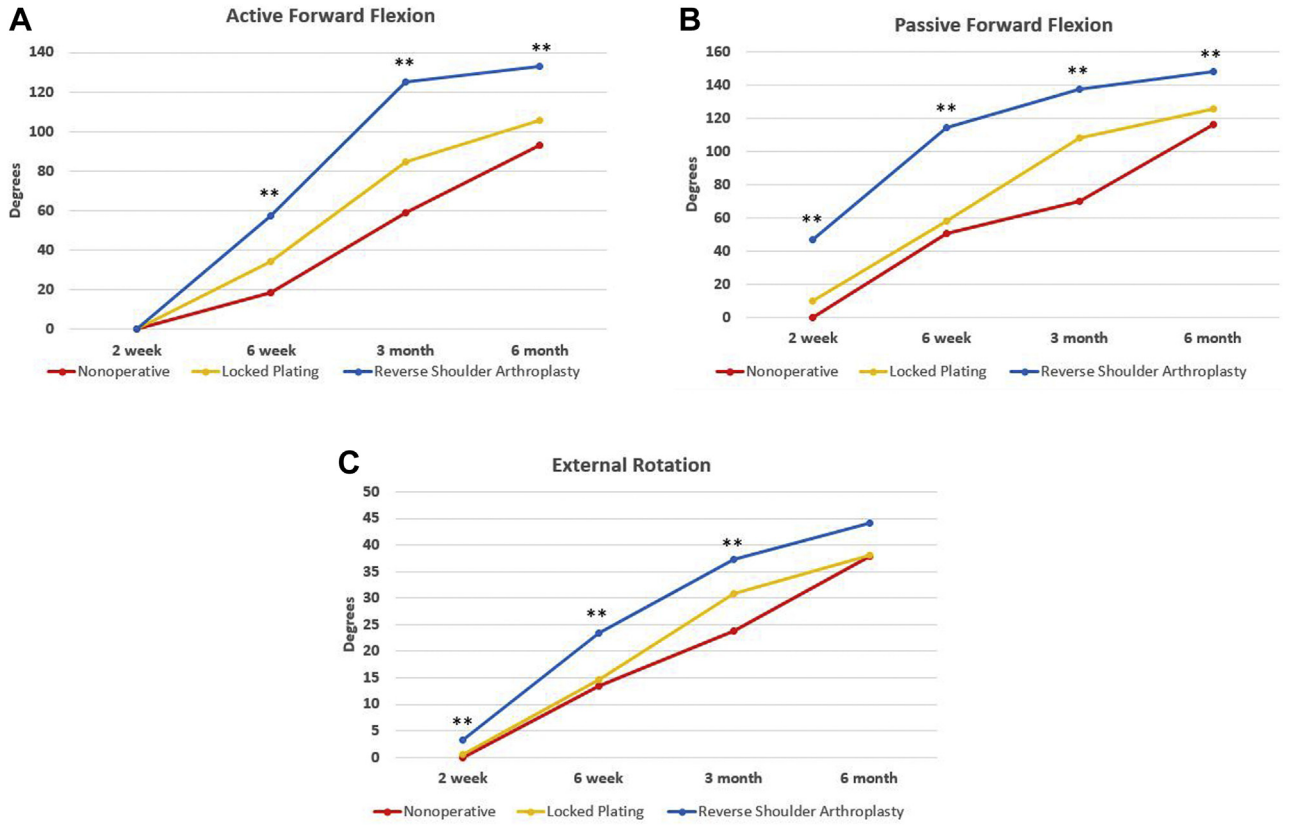

Figure 1 Range of motion data including (**A**) active forward flexion, (**B**) passive forward flexion, and (**C**) external rotation among nonoperative, ORIF, and RSA cohorts at 2 weeks, 6 weeks, 3 months, and 6 months. ** = statistically significant difference between groups. *ORIF*, open reduction internal fixation; *RSA*, reverse shoulder arthroplasty.

Table III
Patient-reported outcomes

	Nonoperative (N = 41)	ORIF (N = 23)	RSA (N = 24)	*P* value*
VAS pain score (mean ± SD)				
2-week follow-up	6.2 ± 3.3	2.4 ± 2.2	2.7 ± 2.6	**<.01**
6-week follow-up	3.5 ± 2.9	2.1 ± 2.5	1.1 ± 1.7	**<.01**
3-month follow-up	1.9 ± 2.1	1.5 ± 1.7	1.1 ± 2.0	.33
6-month follow-up	1.7 ± 2.3	1.1 ± 1.5	0.8 ± 1.6	.24
1-yr follow-up	0.6 ± 1.3	1.7 ± 1.4	0.1 ± 0.3	**<.01**
PROMIS pain interference (mean ± SD)				
2-week follow-up	68.9 ± 5.8	64.1 ± 7.2	63.8 ± 6.9	**.02**
6-week follow-up	61.0 ± 5.9	57.3 ± 4.4	57.4 ± 5.7	**.04**
3-month follow-up	59.6 ± 6.1	55.2 ± 6.4	50.0 ± 7.3	**<.01**
6-month follow-up	57.9 ± 8.5	52.7 ± 7.8	53.3 ± 6.0	.10
1-yr follow-up	58.4 ± 9.7	50.3 ± 7.5	51.2 ± 5.9	.07
PROMIS physical function (mean ± SD)				
2-week follow-up	28.4 ± 6.9	31.3 ± 6.0	28.3 ± 4.8	.23
6-week follow-up	30.7 ± 4.9	35.9 ± 5.4	33.8 ± 4.4	**<.01**
3-month follow-up	35.4 ± 8.7	40.8 ± 5.5	39.0 ± 4.3	**.045**
6-month follow-up	37.4 ± 8.5	44.8 ± 5.6	42.2 ± 5.2	**.01**
1-yr follow-up	37.9 ± 7.7	48.1 ± 8.2	46.0 ± 4.7	**.01**
PROMIS depression (mean ± SD)				
2-week follow-up	58.1 ± 9.1	53.0 ± 8.9	55.8 ± 7.0	.18
6-week follow-up	52.3 ± 9.2	52.0 ± 7.7	52.8 ± 7.3	.96
3-month follow-up	51.0 ± 8.5	47.7 ± 7.1	49.3 ± 10.2	.47
6-month follow-up	51.3 ± 9.9	45.9 ± 10.6	46.8 ± 10.6	.27
1-yr follow-up	49.7 ± 7.7	43.4 ± 8.0	47.1 ± 8.6	.24

ORIF, open reduction internal fixation; *RSA*, reverse shoulder arthroplasty; *PROMIS*, Patient-Reported Outcomes Measurement Information System; *SD*, standard deviation; *VAS*, visual analog scale.
Boldface indicates statistical significance.
**P* values calculated using analysis of variance.

groups at 1 year. In addition, early increases in ROM were demonstrated by the surgical cohorts compared to nonoperative treatment, with RSA leading to the greatest amount of motion, which was sustained at the 1-year follow-up. ORIF in this study led to higher complications rates than the nonoperative and RSA cohorts. ORIF had higher secondary operations within the first 2

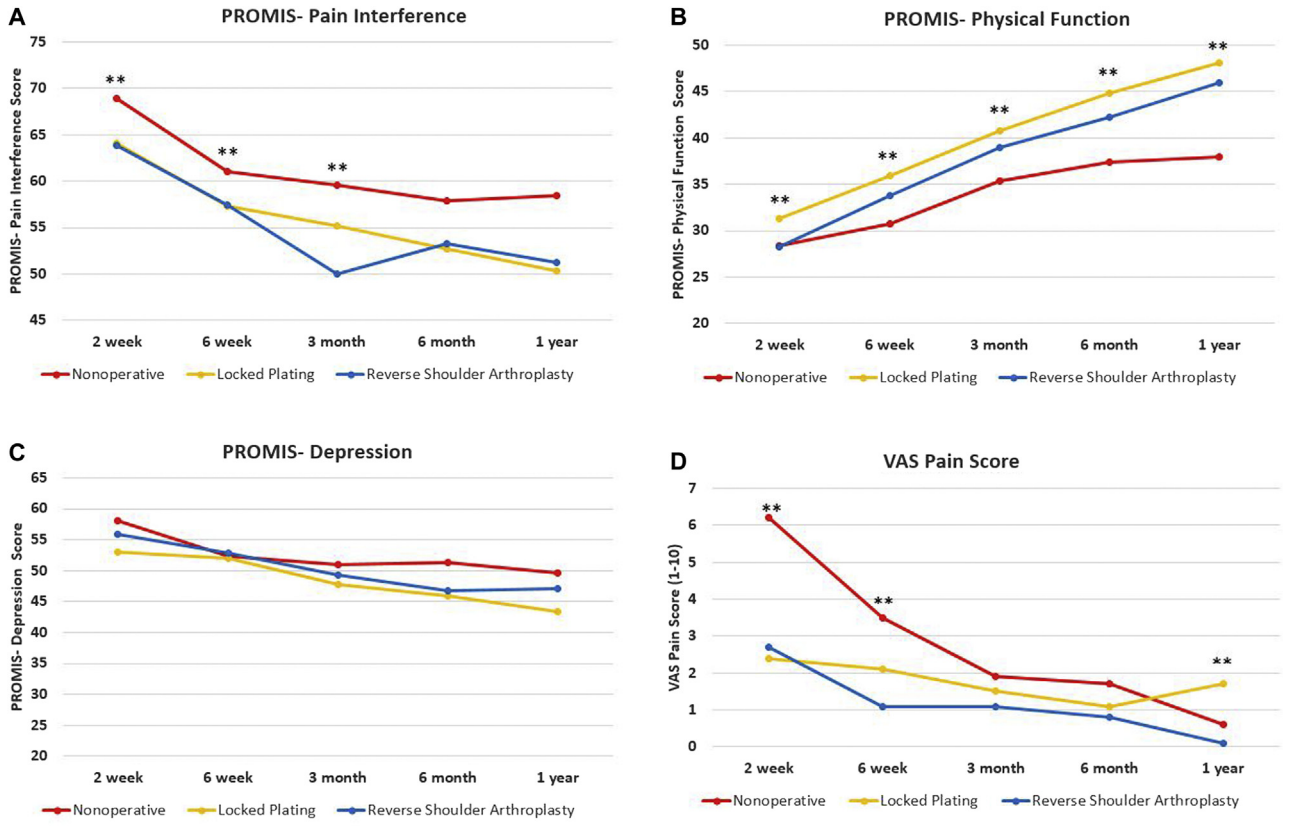

Figure 2 Patient Reported Outcomes including (**A**) PROMIS pain interference, (**B**) physical function, (**C**) depression, and (**D**) VAS pain scores among nonoperative, ORIF, and RSA cohorts at 2 weeks, 6 weeks, 3 months, 6 months, and 1 year. ** = statistically significant difference between groups. *VAS*, visual analog scale; *ORIF*, open reduction internal fixation; *RSA*, reverse shoulder arthroplasty.

Table IV
Complications

	Nonoperative (N = 41)	ORIF (N = 23)	RSA (N = 24)	*P* value*
Malunion (n)	77.5% (31)	38.9% (7)	–	**<.01**
Complications (n)†	9.8% (4)	34.8% (8)	4.2% (1)	**<.01**
Secondary operation (n)‡	4.9% (2)	34.8% (8)	0.0% (0)	**<.01**

ORIF, open reduction internal fixation; *RSA*, reverse shoulder arthroplasty.
Boldface indicates statistical significance.
**P* values calculated using chi square analysis.
†Complications: Nonoperative – nonunion (1), avascular necrosis (3), ORIF, avascular necrosis (3), screw cutout (1), hardware failure (2), adhesive capsulitis (2), RSA, periprosthetic fracture (1).
‡Secondary operations: Nonoperative – conversion to arthroplasty (2); ORIF, conversion to arthroplasty (4), revision fixation (1), removal of hardware (1), lysis of adhesions (2).

years after treatment, whereas no secondary operations occurred among the RSA group.

Surgical treatment of AO/OTA type C fractures was associated with a significant reduction in pain early in recovery compared to nonoperative treatment. The most dramatic differences between the groups were observed at the 2-week follow-up visit, although these differences converged over time. Calvaro et al[9] similarly reported early increased pain, decreased functional capacity, and reduction in patient-perceived health associated with nonoperative management. Sixty-seven percent of the patients reported moderate-extreme pain or discomfort early in recovery for nondisplaced proximal humerus fractures. Similar to our study, meta-analysis and randomized studies report equivalent pain scores at 6 months, 1 year, and 2 years after injury between nonoperative and surgical treatments.[21,22] However, these studies did not record outcomes prior to 6 months, which limits their assessment of short-term pain improvement. There was a slight increase in the visual analog scale pain score for the ORIF group at the 1-year mark compared to the nonoperative and RSA groups; however, this was not reflected in the PROMIS pain interference scores. This may be related to the limited sample size of our study or differences between these outcome measures. Our study suggests that surgical treatment significantly reduces pain in the early recovery of AO/OTA type C proximal humerus fractures compared to non-operative treatment, which may be an important consideration to discuss with patients as this may lead to reduced narcotic use and earlier return to activities of daily living. It is noteworthy that RSA had quicker improvement in pain postoperatively. However, it remains unclear if the statistical values associated with pain relief are of clinical significance, and further investigation is warranted.

AO/OTA type C proximal humerus fractures managed surgically demonstrated improved early ROM compared to nonoperative

management, with RSA appearing to outperform both ORIF and nonoperative management. RSA had a significantly better pFF at 2 weeks than the ORIF and nonoperative cohorts likely secondary to difference in rehabilitation protocols among the groups. Notably, at the 2-week follow-up, all patients demonstrated similar aFF and ER because active ROM is not part of the rehabilitation protocol at our institution early in recovery for all 3 treatment groups. As a result, ROM data at this time point are of limited clinical utility. PROMIS physical function scores were also significantly better in the surgical cohorts than the nonoperative group at the 6-week, 6-month, and 1-year follow-up visits. Similar studies suggest that surgical treatment significantly improves ROM and physical function in the early recovery of AO/OTA type C proximal humerus fractures.[7,30,39,51,52] Two studies directly comparing ORIF, HA, and RSA also support good function outcomes associated with surgical treatment of proximal humerus fractures.[11,56] Similar to our study, others have demonstrated superior early ROM and shoulder function after RSA compared to nonoperative management and ORIF; however, none have directly compared all 3.[11,13] Improved ROM metrics were seen at the final follow-up for the RSA and ORIF groups as highlighted by significantly higher achievement of satisfactory functional outcomes (aFF >90°) than the nonoperative group. Our study suggests that surgical treatment significantly improves ROM and physical function in the early recovery of AO/OTA type C proximal humerus fractures compared to nonoperative treatment in adult patients older than the age of 60 years.

Conversely, Li et al[35] performed a meta-analysis on nonoperative management compared to ORIF, which did not show a difference in functional outcome, but did show a significantly higher complication rate in the ORIF group. Additional studies further support good outcomes for AO/OTA type C fractures with nonoperative management compared to ORIF.[21,43,59] Differences between our results and these prior investigations may be related to differences in age, patient demographics, and fracture morphology categorization. While early results for RSA are promising, some studies express caution when using RSA for proximal humerus fractures.[57] Additional literature suggests that RSA should be utilized exclusively for very disabling shoulder pathology and in patients older than 70 years of age.[20] However, improved techniques along with good clinical outcomes for RSA provide support for broadening the indications for RSA usage in treating proximal humerus fractures in adults older than the age of 60 years.[1,5,6,13,25,26,28] The results of this short-term study provide a foundation for directly comparing nonoperative to surgical treatment for complex proximal humerus fractures in adult patients. Furthermore, mid-term and long-term studies are needed to evaluate whether these short-term benefits are sustained and clinically significant for activities of daily living and to determine the rate of medium- and long-term complications of RSA specifically for the treatment of proximal humerus fractures.

When deciding how to treat AO/OTA type C fractures, complications and reoperation rate among treatment options play an important role in the decision-making process. Overall complication rates were higher in the ORIF group than in the nonoperative and RSA groups. The secondary operation rate was also higher in the ORIF group than in the nonoperative and RSA groups. Prior studies also report higher complication and reoperation rates with ORIF.[7,30,35,41,51,52] The most common complications following RSA include instability (4.7%), infection (4%), scapular notching (35%), acromion/scapula fractures (1.5%), periprosthetic fracture, tuberosity resorption, and tuberosity malunion/nonunion.[3,12,20,58] This is consistent with the results of our study. Zumstein et al[58] conducted a systematic review for complications, reoperations, and revisions after RSA for rotator cuff arthropathy and reported rates of 24%, 3.5%, and 10%, respectively. The time frame for associated glenoid loosening from scapular notching in this review was 114 months. Other studies have previously reported mid-term survivorship for RSA as 76% to 91% at 10 years, with early loosening occurring within the first 3 years postoperatively. Additional studies report reoperation rates of 14.4% and revision rates of 11.2% in patients younger than 65 years treated with RSA.[19,20] The observed differences between our study's complication and reoperation rate and prior studies are likely explained by the short-term design of our study, limited sample size, and variable definitions of complications. Scapular notching is important for the long-term follow-up for possible bone resorption, glenoid loosening, and possible revision surgery; however, we did not include it as a complication in the present study because our goal was to evaluate short-term outcomes, of which scapular notching has less relevance in the short term. Our scapular notching rate is consistent with prior studies mentioned previously. Mid- and long-term follow-up is needed to assess the true risk of complication and reoperation rates in the RSA cohort specifically for the treatment of proximal humerus fractures. Nonetheless, RSA had a lower complication and reoperation rate than ORIF treatment, which is supported by prior studies.[34,48,58] This suggests RSA is a safe treatment option for proximal humerus fractures in the short term in adults older than 60 years. Mid-term studies have been performed on RSA for rotator cuff arthropathy, which show stability to decreased shoulder outcome scores at 10 to 15 years, which correlate with implant survivorship and retention.[4,19,58] However, further dedicated studies are needed to elucidate the mid-term and long-term survivorship of RSA specifically for complex proximal humerus fractures in the adult population compared to ORIF or conservative management.

This study is subject to several limitations. Our study introduces an element of selection bias due to the lack of randomization or algorithmic selection. Treatment decisions were made at the surgeon's discretion and likely influenced by a myriad of factors including surgeon and patient preferences, patient age, comorbidities, functional status, and fracture characteristics. In addition, there was a relatively small sample size, which may have limited the statistical power and increases the possibility of type II error. An additional limitation is ROM data documentation at the 1-year time point. While the reasons for this are likely multifactorial, patients were often no longer participating in physical therapy at this time point, and therefore, ROM measurements were less consistent. As such, ROM analysis was only performed up to the 6-month follow-up time point. Furthermore, patients may have developed complications or required a secondary operation outside of 1 year that were not captured in the results of this study, reflecting the limitations of the short-term follow-up from the study design. This is particularly important regarding the RSA group. Another limitation of this study is that the use of PROMIS is not disease specific and could be influenced by other pathology producing pain or interfering with physical function; however, PROMIS has been shown to correlate strongly with conventional measures of upper extremity function (Constant score, DASH, SMFA, ASES).[18] Patient's age, health, function, compliance with rehabilitation, and postoperative restrictions should all be taken into account when considering nonoperative management, ORIF, and RSA treatments. Despite these limitations, this is the largest sample to date directly comparing the nonoperative, ORIF, and RSA cohorts for type C proximal humerus fractures in adults older than 60 years and serves as an important foundation for future mid- and long-term studies.

Conclusion

The results of this study indicate that management of geriatric AO/OTA type C proximal humerus fractures with RSA is associated

with the greatest postoperative ROM, followed by ORIF, then nonoperative management. Additionally, operative treatment with either RSA or ORIF leads to earlier improvements in pain and physical function compared to nonoperative management, despite higher complication and secondary operation rates after ORIF. This information will be important when counseling patients regarding treatment options and recovery expectations. The results from this study create a foundation for which future mid- and long-term prospective trials to further create an algorithmic approach and delineate the optimal treatment for AO/OTA type C proximal humerus fractures in the adult population.

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References

1. Acevedo DC, Vanbeek C, Lazarus MD, Williams GR, Abboud JA. Reverse shoulder arthroplasty for proximal humeral fractures: update on indications, technique, and results. J Shoulder Elbow Surg 2014;23:279-89. https://doi.org/10.1016/j.jse.2013.10.003.
2. Agudelo J, Schürmann M, Stahel P, Helwig P, Morgan SJ, Zechel W, et al. Analysis of efficacy and failure in proximal humerus fractures treated with locking plates. J Orthop Trauma 2007;21:676-81. https://doi.org/10.1097/BOT.0b013e31815bb09d.
3. Anakwenze OA, Zoller S, Ahmad CS, Levine WN. Reverse shoulder arthroplasty for acute proximal humerus fractures: a systematic review. J Shoulder Elbow Surg 2014;23:e73-80. https://doi.org/10.1016/j.jse.2013.09.012.
4. Bacle G, Nové-Josserand L, Garaud P, Walch G. Long-term outcomes of reverse total shoulder arthroplasty: a follow-up of a previous study. J Bone Joint Surg Am 2017;99:454-61. https://doi.org/10.2106/jbjs.16.00223.
5. Boileau P, Krishnan SG, Tinsi L, Walch G, Coste JS, Molé D. Tuberosity malposition and migration: reasons for poor outcomes after hemiarthroplasty for displaced fractures of the proximal humerus. J Shoulder Elbow Surg 2002;11:401-12. https://doi.org/10.1067/mse.2002.124527.
6. Boileau P, Watkinson DJ, Hatzidakis AM, Balg F. Grammont reverse prosthesis: design, rationale, and biomechanics. J Shoulder Elbow Surg 2005;14:147s-61s. https://doi.org/10.1016/j.jse.2004.10.006.
7. Brunner F, Sommer C, Bahrs C, Heuwinkel R, Hafner C, Rillmann P, et al. Open reduction and internal fixation of proximal humerus fractures using a proximal humeral locked plate: a prospective multicenter analysis. J Orthop Trauma 2009;23:163-72. https://doi.org/10.1097/BOT.0b013e3181920e5b.
8. Cadet ER, Ahmad CS. Hemiarthroplasty for three- and four-part proximal humerus fractures. J Am Acad Orthop Surg 2012;20:17-27. https://doi.org/10.5435/jaaos-20-01-017.
9. Calvo E, Morcillo D, Foruria AM, Redondo-Santamaría E, Osorio-Picorne F, Caeiro JR. Nondisplaced proximal humeral fractures: high incidence among outpatient-treated osteoporotic fractures and severe impact on upper extremity function and patient subjective health perception. J Shoulder Elbow Surg 2011;20:795-801. https://doi.org/10.1016/j.jse.2010.09.008.
10. Campochiaro G, Rebuzzi M, Baudi P, Catani F. Complex proximal humerus fractures: Hertel's criteria reliability to predict head necrosis. Musculoskelet Surg 2015;99:S9-15. https://doi.org/10.1007/s12306-015-0358-z.
11. Chalmers PN, Slikker W 3rd, Mall NA, Gupta AK, Rahman Z, Enriquez D, et al. Reverse total shoulder arthroplasty for acute proximal humeral fracture: comparison to open reduction-internal fixation and hemiarthroplasty. J Shoulder Elbow Surg 2014;23:197-204. https://doi.org/10.1016/j.jse.2013.07.044.
12. Cheung E, Willis M, Walker M, Clark R, Frankle MA. Complications in reverse total shoulder arthroplasty. J Am Acad Orthop Surg 2011;19:439-49.
13. Chivot M, Lami D, Bizzozero P, Galland A, Argenson JN. Three- and four-part displaced proximal humeral fractures in patients older than 70 years: reverse shoulder arthroplasty or nonsurgical treatment? J Shoulder Elbow Surg 2019;28:252-9. https://doi.org/10.1016/j.jse.2018.07.019.
14. Clement ND, Duckworth AD, McQueen MM, Court-Brown CM. The outcome of proximal humeral fractures in the elderly: predictors of mortality and function. Bone Joint 2014;96-b:970-7. https://doi.org/10.1302/0301-620x.96b7.32894.
15. Court-Brown CM, Cattermole H, McQueen MM. Impacted valgus fractures (B1.1) of the proximal humerus. The results of non-operative treatment. J Bone Joint Surg Br 2002;84:504-8. https://doi.org/10.1302/0301-620x.84b4.12488.
16. Court-Brown CM, Garg A, McQueen MM. The translated two-part fracture of the proximal humerus. Epidemiology and outcome in the older patient. J Bone Joint Surg Br 2001;83:799-804.
17. Gallinet D, Clappaz P, Garbuio P, Tropet Y, Obert L. Three or four parts complex proximal humerus fractures: hemiarthroplasty versus reverse prosthesis: a comparative study of 40 cases. Orthop Traumatol Surg Res 2009;95:48-55. https://doi.org/10.1016/j.otsr.2008.09.002.
18. Gausden EB, Levack AE, Sin DN, Nwachukwu BU, Fabricant PD, Nellestein AM, et al. Validating the Patient Reported Outcomes Measurement Information System (PROMIS) computerized adaptive tests for upper extremity fracture care. J Shoulder Elbow Surg 2018;27:1191-7. https://doi.org/10.1016/j.jse.2018.01.014.
19. Goldenberg BT, Samuelsen BT, Spratt JD, Dornan GJ, Millett PJ. Complications and implant survivorship following primary reverse total shoulder arthroplasty in patients younger than 65 years: a systematic review. J Sshoulder Elbow Surg 2020;29:1703-11. https://doi.org/10.1016/j.jse.2020.02.004.
20. Guery J, Favard L, Sirveaux F, Oudet D, Mole D, Walch G. Reverse total shoulder arthroplasty. Survivorship analysis of eighty replacements followed for five to ten years. J Bone Joint Surg Am 2006;88:1742-7. https://doi.org/10.2106/jbjs.E.00851.
21. Handoll H, Brealey S, Rangan A, Keding A, Corbacho B, Jefferson L, et al. The ProFHER (PROximal Fracture of the Humerus: Evaluation by Randomisation) trial - a pragmatic multicentre randomised controlled trial evaluating the clinical effectiveness and cost-effectiveness of surgical compared with non-surgical treatment for proximal fracture of the humerus in adults. Health Technol Assess 2015;19:1-280. https://doi.org/10.3310/hta19240.
22. Handoll HH, Brorson S. Interventions for treating proximal humeral fractures in adults. Cochrane Database Syst Rev 2015;11:Cd000434. https://doi.org/10.1002/14651858.CD000434.pub4.
23. Hardeman F, Bollars P, Donnelly M, Bellemans J, Nijs S. Predictive factors for functional outcome and failure in angular stable osteosynthesis of the proximal humerus. Injury 2012;43:153-8. https://doi.org/10.1016/j.injury.2011.04.003.
24. Hasty EK, Jernigan EW 3rd, Soo A, Varkey DT, Kamath GV. Trends in surgical management and costs for operative treatment of proximal humerus fractures in the elderly. Orthopedics 2017;40:e641-7. https://doi.org/10.3928/01477447-20170411-03.
25. Henninger HB, Barg A, Anderson AE, Bachus KN, Burks RT, Tashjian RZ. Effect of lateral offset center of rotation in reverse total shoulder arthroplasty: a biomechanical study. J Shoulder Elbow Surg 2012;21:1128-35. https://doi.org/10.1016/j.jse.2011.07.034.
26. Henninger HB, Barg A, Anderson AE, Bachus KN, Tashjian RZ, Burks RT. Effect of deltoid tension and humeral version in reverse total shoulder arthroplasty: a biomechanical study. J Shoulder Elbow Surg 2012;21:483-90. https://doi.org/10.1016/j.jse.2011.01.040.
27. Hertel R, Hempfing A, Stiehler M, Leunig M. Predictors of humeral head ischemia after intracapsular fracture of the proximal humerus. J Shoulder Ebow Surg 2004;13:427-33. https://doi.org/10.1016/j.jse.2004.01.034.
28. Jobin CM, Galdi B, Anakwenze OA, Ahmad CS, Levine WN. Reverse shoulder arthroplasty for the management of proximal humerus fractures. J Am Acad Orthop Surg 2015;23:190-201. https://doi.org/10.5435/jaaos-d-13-00190.
29. Kancherla VK, Singh A, Anakwenze OA. Management of acute proximal humeral fractures. J Am Acad Orthop Surg 2017;25:42-52. https://doi.org/10.5435/jaaos-d-15-00240.
30. Konrad G, Bayer J, Hepp P, Voigt C, Oestern H, Kääb M, et al. Open reduction and internal fixation of proximal humeral fractures with use of the locking proximal humerus plate. Surgical technique. J Bone Joint Surg Am 2010;92:85-95. https://doi.org/10.2106/jbjs.I.01462.
31. LaMartina J 2nd, Christmas KN, Simon P, Streit JJ, Allert JW, Clark J, et al. Difficulty in decision making in the treatment of displaced proximal humerus fractures: the effect of uncertainty on surgical outcomes. J Shoulder Elbow Surg 2018;27:470-7. https://doi.org/10.1016/j.jse.2017.09.033.
32. Lander ST, Mahmood B, Maceroli MA, Byrd J, Elfar JC, Ketz JP, et al. Mortality rates of humerus fractures in the elderly: does surgical treatment matter? J Orthop Trauma 2019;33:361-5. https://doi.org/10.1097/bot.0000000000001449.
33. Lehman C, Cuomo F, Kummer FJ, Zuckerman JD. The incidence of full thickness rotator cuff tears in a large cadaveric population. Bull Hosp Jt Dis 1995;54:30-1.
34. Lenarz C, Shishani Y, McCrum C, Nowinski RJ, Edwards TB, Gobezie R. Is reverse shoulder arthroplasty appropriate for the treatment of fractures in the older patient? Early observations. Clin orthopaedics Relat Res 2011;469:3324-31. https://doi.org/10.1007/s11999-011-2055-z.
35. Li Y, Zhao L, Zhu L, Li J, Chen A. Internal fixation versus nonoperative treatment for displaced 3-part or 4-part proximal humeral fractures in elderly patients: a

meta-analysis of randomized controlled trials. PLoS One 2013;8:e75464. https://doi.org/10.1371/journal.pone.0075464.
36. Meinberg EG, Agel J, Roberts CS, Karam MD, Kellam JF. Fracture and dislocation classification compendium-2018. J Orthop Trauma 2018;32:S1-170. https://doi.org/10.1097/bot.0000000000001063.
37. Neer CS 2nd. Displaced proximal humeral fractures. II. Treatment of three-part and four-part displacement. J Bone Joint Surg Am 1970;52:1090-103.
38. Nho SJ, Brophy RH, Barker JU, Cornell CN, MacGillivray JD. Innovations in the management of displaced proximal humerus fractures. J Am Acad Orthop Surg 2007;15:12-26. https://doi.org/10.5435/00124635-200701000-00003.
39. Olerud P, Ahrengart L, Ponzer S, Saving J, Tidermark J. Internal fixation versus nonoperative treatment of displaced 3-part proximal humeral fractures in elderly patients: a randomized controlled trial. J Shoulder Elbow Surg 2011;20:747-55. https://doi.org/10.1016/j.jse.2010.12.018.
40. Orman S, Mohamadi A, Serino J, Murphy J, Hanna P, Weaver MJ, et al. Comparison of surgical and non-surgical treatments for 3- and 4-part proximal humerus fractures: a network meta-analysis. Shoulder Elbow 2020;12:99-108. https://doi.org/10.1177/1758573219831506.
41. Owsley KC, Gorczyca JT. Fracture displacement and screw cutout after open reduction and locked plate fixation of proximal humeral fractures [corrected]. J Bone Joint Surg Am 2008;90:233-40. https://doi.org/10.2106/jbjs.F.01351.
42. Paavolainen P, Björkenheim JM, Slätis P, Paukku P. Operative treatment of severe proximal humeral fractures. Acta Orthop Scand 1983;54:374-9.
43. Rangan A, Handoll H, Brealey S, Jefferson L, Keding A, Martin BC, et al. Surgical vs nonsurgical treatment of adults with displaced fractures of the proximal humerus: the PROFHER randomized clinical trial. JAMA 2015;313:1037-47. https://doi.org/10.1001/jama.2015.1629.
44. Rasmussen S, Hvass I, Dalsgaard J, Christensen BS, Holstad E. Displaced proximal humeral fractures: results of conservative treatment. Injury 1992;23:41-3.
45. Ross M, Hope B, Stokes A, Peters SE, McLeod I, Duke PF. Reverse shoulder arthroplasty for the treatment of three-part and four-part proximal humeral fractures in the elderly. J Shoulder Elbow Surg 2015;24:215-22. https://doi.org/10.1016/j.jse.2014.05.022.
46. Schairer WW, Nwachukwu BU, Lyman S, Craig EV, Gulotta LV. Reverse shoulder arthroplasty versus hemiarthroplasty for treatment of proximal humerus fractures. J Shoulder Elbow Surg 2015;24:1560-6. https://doi.org/10.1016/j.jse.2015.03.018.
47. Schnetzke M, Bockmeyer J, Porschke F, Studier-Fischer S, Grutzner PA, Guehring T. Quality of reduction influences outcome after locked-plate fixation of proximal humeral type-C fractures. J Bone Joint Surg Am 2016;98:1777-85. https://doi.org/10.2106/JBJS.16.00112.
48. Sebastiá-Forcada E, Cebrián-Gómez R, Lizaur-Utrilla A, Gil-Guillén V. Reverse shoulder arthroplasty versus hemiarthroplasty for acute proximal humeral fractures. A blinded, randomized, controlled, prospective study. J Shoulder Elbow Surg 2014;23:1419-26. https://doi.org/10.1016/j.jse.2014.06.035.
49. Shortt NL, Robinson CM. Mortality after low-energy fractures in patients aged at least 45 years old. J Orthop Trauma 2005;19:396-400. https://doi.org/10.1097/01.bot.0000155311.04886.7e.
50. Shukla DR, McAnany S, Kim J, Overley S, Parsons BO. Hemiarthroplasty versus reverse shoulder arthroplasty for treatment of proximal humeral fractures: a meta-analysis. J Shoulder Elbow Surg 2016;25:330-40. https://doi.org/10.1016/j.jse.2015.08.030.
51. Solberg BD, Moon CN, Franco DP, Paiement GD. Locked plating of 3- and 4-part proximal humerus fractures in older patients: the effect of initial fracture pattern on outcome. J Orthop Trauma 2009;23:113-9. https://doi.org/10.1097/BOT.0b013e31819344bf.
52. Solberg BD, Moon CN, Franco DP, Paiement GD. Surgical treatment of three and four-part proximal humeral fractures. J Bone Joint Surg Am 2009;91:1689-97. https://doi.org/10.2106/jbjs.H.00133.
53. Spross C, Meester J, Mazzucchelli RA, Puskás GJ, Zdravkovic V, Jost B. Evidence-based algorithm to treat patients with proximal humerus fractures-a prospective study with early clinical and overall performance results. J Shoulder Ebow Surg 2019;28:1022-32. https://doi.org/10.1016/j.jse.2019.02.015.
54. Tingart MJ, Apreleva M, von Stechow D, Zurakowski D, Warner JJ. The cortical thickness of the proximal humeral diaphysis predicts bone mineral density of the proximal humerus. J Bone Joint Surg Br 2003;85:611-7. https://doi.org/10.1302/0301-620x.85b4.12843.
55. Valenti P, Katz D, Kilinc A, Elkholti K, Gasiunas V. Mid-term outcome of reverse shoulder prostheses in complex proximal humeral fractures. Acta Orthop Belg 2012;78:442-9.
56. Yahuaca BI, Simon P, Christmas KN, Patel S, Gorman RA 2nd, Mighell MA, et al. Acute surgical management of proximal humerus fractures: ORIF vs. hemiarthroplasty vs. reverse shoulder arthroplasty. J Shoulder Elbow Surg 2020;29:S32-40. https://doi.org/10.1016/j.jse.2019.10.012.
57. Young SW, Segal BS, Turner PC, Poon PC. Comparison of functional outcomes of reverse shoulder arthroplasty versus hemiarthroplasty in the primary treatment of acute proximal humerus fracture. ANZ J Surg 2010;80:789-93. https://doi.org/10.1111/j.1445-2197.2010.05342.x.
58. Zumstein MA, Pinedo M, Old J, Boileau P. Problems, complications, reoperations, and revisions in reverse total shoulder arthroplasty: a systematic review. J Shoulder Elbow Surg 2011;20:146-57. https://doi.org/10.1016/j.jse.2010.08.001.
59. Zyto K. Non-operative treatment of comminuted fractures of the proximal humerus in elderly patients. Injury 1998;29:349-52.