JSES International 4 (2020) 734–738

Contents lists available at ScienceDirect

JSES International

journal homepage: www.jsesinternational.org

Risk factors for nonunion after traumatic humeral shaft fractures in adults

Jeffrey J. Olson, MD [1], Vahid Entezari, MD, MMSc [1], Heather A. Vallier, MD *

Study Performed at MetroHealth Medical Center, Affiliated with Case Western Reserve University, Cleveland, OH, USA

A R T I C L E I N F O

Keywords:
Humeral shaft fractures
open reduction internal fixation
functional bracing
nonunion
outcomes
complications

Level of evidence: Level III; Retrospective Cohort Comparison; Treatment Study

Introduction: Humeral shaft fractures account for 3% of adult fractures. Optimal management remains a topic of debate given variable union rates reported in the literature after surgery or functional bracing. The primary aim was to compare these 2 cohorts of patients and their primary fracture union rates. A secondary aim was to identify predictors of nonunion.

Methods: A retrospective cohort study of 164 adult patients with traumatic humeral shaft fractures was performed. Fractures were classified according to the Arbeitsgemeinschaft für Osteosynthesefragen/Orthopaedic Trauma Association classification. Primary outcomes included rate nonunion, including symptomatic fractures requiring conversion to open reduction and internal fixation (ORIF). Secondary outcomes included rates of complications and secondary procedures.

Results: Ninety-four (57%) patients were treated initially with ORIF. Nonoperative patients were older (47.1 vs. 41.5 years, $P = .028$) and had more medical comorbidity (62% vs. 43%, $P = .017$), low-energy trauma (62% vs. 34%, $P < .0001$), and isolated injuries (74% vs. 32%, $P < .0001$). All patients with open fractures (23%) were treated with débridement and ORIF, and surgical patients had more nerve injuries on presentation (36% vs. 9%, $P < .0001$). The overall rate of primary fracture union was 88%, similar after ORIF and nonoperative management (92% vs. 83%, $P = .095$). Multivariate analysis found alcohol abuse (odds ratio [OR]: 3.4, 95% confidence interval [CI]: 1.0-11.0, $P = .046$) and deep infection (OR: 19.9, 95% CI: 2.6-150.5, $P = .004$) to be significant predictors of nonunion. Chronic liver disease demonstrated a trend toward increased risk of nonunion (OR: 4.1, 95% CI: 0.8-20.9, $P = .088$). Seventeen operative patients (18%) developed 17 postoperative complications: iatrogenic nerve palsy (5%), deep infection (5%), and implant failure (3%), the most common. Reoperation rate was 10%, primarily for revision ORIF (4%).

Conclusion: Patients managed nonoperatively were more often older patients with isolated fractures and more medical comorbidity. Surgical candidates were younger, more often with higher energy injuries, and were frequently with concomitant injury. Primary union occurred in 88%, with a trend toward a higher rate after ORIF. Patients with chronic liver disease and/or alcohol abuse are at greater risk for nonunion, irrespective of treatment.

Humeral shaft fractures account for approximately 3% of all adult fractures and 20% of all humeral fractures. Elderly patients sustain these injuries commonly after ground-level falls. Fractures in younger patients tend to occur after high-energy blunt trauma or penetrating injury. Union rates after nonoperative management vary widely in the literature. Early studies demonstrated high (95%-97%) union rates after functional bracing, popularized by Sarmiento. However, more recent studies suggest that the rate of nonunion after nonoperative treatment can be as high as 14%-23%, and up to 29% of patients eventually undergo open reduction and internal fixation (ORIF) after nonoperative treatment.[1,3,24,28,33,34] Large retrospective series evaluating surgical management demonstrate union rates between 84% and 97%[2,7,11,15,20,31,34] and no difference between compression plating and intramedullary nailing.[14,17] In contrast to nonoperative management, surgery incurs a higher initial treatment cost and is associated with complications including infection (3%-15%) and iatrogenic nerve palsy (1.5%-10%).[5,6,8,14,17,25,26,34] Secondary operation rates also range between 14% and 36%. To date, few studies have compared nonoperative vs. operative management, with only 2 small randomized trials.[12,16] These studies did not determine predictors of nonunion. The purpose of this study was 2-fold: (1) to compare patient and

Approval for this study was received from MetroHealth Institutional Review Board (Registration no. IRB00000685).

* Corresponding author: Heather A. Vallier, MD, Department of Orthopaedic Surgery, 2500 MetroHealth Drive, Cleveland, OH 44109, USA.

E-mail address: hvallier@metrohealth.org (H.A. Vallier).

[1] These authors contributed equally to this work and agree to share lead authorship.

https://doi.org/10.1016/j.jseint.2020.06.009

fracture characteristics and the rates of nonunion for nonoperative and operative cohorts and (2) to identify predictors of nonunion.

Materials and methods

Study design and data collection

One hundred sixty-four adult patients with humeral shaft fractures who presented to an urban level I trauma center between 2000 and 2015 were included. Inclusion and exclusion criteria are demonstrated in Fig. 1. Demographic, medical comorbidity, self-reported alcohol and tobacco use, fracture location and pattern, mechanism of injury, and nerve and vascular injury data were collected. Alcohol abuse was defined as self-reported alcohol consumption consistent with the Center for Disease Control and Prevention and American Dietary guidelines definition of excessive alcohol use (>4 drinks per day or >8 drinks per week for women and >5 drinks per day of 15 drinks per week for men). Patients with alcohol-related medical comorbidities (EtOH cirrhosis, malnutrition) or patients whose injury was related to alcohol use were included.[4,32] Initial injury radiographs were used to classify the fracture pattern using the Arbeitsgemeinschaft für Osteosynthesefragen/Orthopaedic Trauma Association classification by consensus among 3 trained examiners.[18]

Treatment

Nonoperative management consisted of application of a coaptation or long-arm splint in the emergency department followed by functional bracing after 7-10 days. Patients who were indicated for operative management underwent ORIF using plate osteosynthesis by a fellowship-trained trauma or upper extremity surgeon followed by a period of 1-2 weeks of rest for wound healing. Thereafter, free use of the arm was allowed for activities of daily living and weight-bearing. Fracture healing was assessed by appearance of bridging callous or resolution of radiolucent fracture line on 3 or 4 cortices of biplanar plain radiographs, combined with resolution of functional pain at the fracture site.

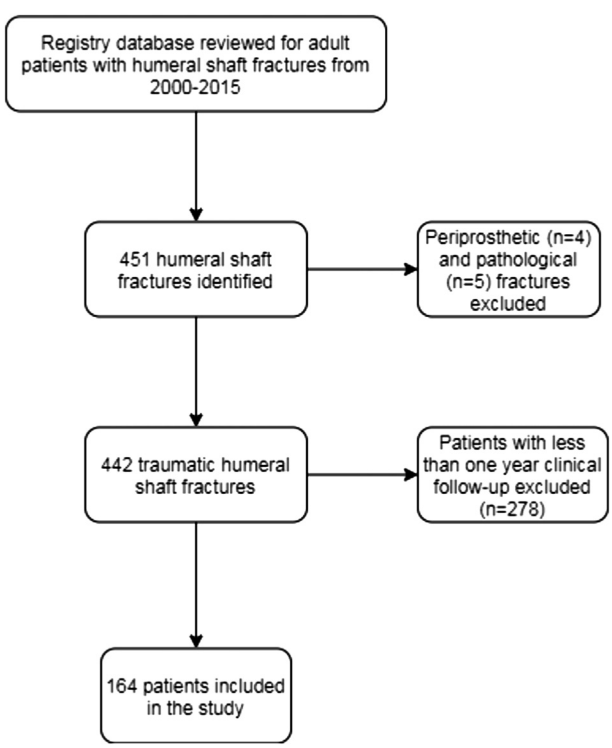

Figure 1 Inclusion and exclusion criteria used to identify the final 164 patients included in the study.

Outcomes

Primary outcomes of interest were nonunion and symptomatic fracture requiring conversion to ORIF. Symptomatic fracture was defined as continued pain with lack of radiographic healing between 6 and 24 weeks. Nonunion was defined lack of radiographic healing after 24 weeks.[13] Secondary outcome measures included postoperative complications rates including iatrogenic nerve palsy, deep infection requiring return to operating room for débridement, and secondary procedures.

Statistical analysis

Statistical analysis was performed using SPSS software (version 22.0; SPSS Inc./IBM, Chicago, IL, USA). Results are presented as mean ± standard deviation and median ± interquartile range for continuous variables and as number and percentages for categorical data. Student's *t*-test and Mann-Whitney test for the analysis of normally and non-normally distributed data were applied accordingly. χ^2 and Fisher's exact tests were used for categorical data. Univariate logistic regression was used to identify individual predictors of nonunion. Potential covariates ($P < .2$) and cofounders were included in the multivariate analysis.[27] A backward-elimination method logistic regression adjusting for potential confounding variables was used to create a final model for predictors of nonunion. Results are presented as odds ratios (OR) with 95% confidence intervals (CI). *P* values of less than .05 were considered statistically significant.

Results

The summary of patient demographics and medical comorbidities is provided in Table I. Overall, 95 patients were male (58%), with the mean age of 45 years. The presence of any medical comorbidity was noted in 51% of patients: hypertension (31%), diabetes (12%), coronary disease (7%), and chronic liver disease (5%), the most common. Tobacco use (46%) and alcohol abuse (45%) also occurred frequently. Patients managed nonoperatively were, on average, older (47.1 vs. 41.5 years, $P = .028$) and were more likely to have at least 1 medical comorbidity (62% vs. 43%, $P = .017$). Those with chronic liver disease were more often managed nonoperatively (88% vs. 13%, $P = .021$), and a trend was noted for those with a history of alcohol abuse to be treated nonoperatively (53% vs. 39%, $P = .086$).

The majority of patients sustained injuries after a high-energy mechanism (59%) (Table II). Falls from standing height occurred in 42 patients (26%), and of those, 31 (74%) underwent initial nonoperative management. Open fractures comprised 13% of injuries, and all were treated with urgent surgical irrigation and débridement and ORIF. Primary nerve palsy was found in 24% of patients, with radial nerve (81%) the most commonly injured nerve. Fractures demonstrated a relatively even distribution of proximal-third (29%), middle-third (42%), and distal-third (29%) shaft fractures. See Table III. According to the Arbeitsgemeinschaft für Osteosynthesefragen/Orthopaedic Trauma Association classification, most fractures were simple type A (47%), followed by type B (27%) and type C (26%). Simple type A fractures were more often treated with ORIF (33 of 55 fractures [60%]).

Ninety-four patients (57%) initially underwent ORIF at mean 3.8 days (range, 0-28 days) after injury, and 86 (92%) healed uneventfully. Of the 8 nonunions in the primary operative group (8.5%), 7 underwent revision ORIF at mean 46 (3-80) weeks

Table I
Baseline demographics and medical comorbidities are shown for all patients and for those in the initial operative and nonoperative groups

	All (n = 164)	Operative (n = 94)	Nonoperative (n = 70)	*P* value
Mean (SD) age (yr)	**44.9**	**41.5 (15.9)**	**47.1 (16.5)**	**.028**
Male sex	95 (58%)	55 (59%)	40 (57%)	.42
Mean BMI	30.5	30.1	29.7	.78
Comorbidity	**83 (51%)**	**40 (43%)**	**43 (62%)**	**.017**
Coronary disease	11 (7%)	5 (5%)	6 (9%)	.41
HTN	**50 (31%)**	**20 (21%)**	**30 (43%)**	**.003**
Diabetes	19 (12%)	8 (9%)	11 (16%)	.15
COPD	6 (4%)	5 (5%)	1 (1%)	.19
Chronic liver disease	**8 (5%)**	**1 (1%)**	**7 (10%)**	**.021**
Chronic kidney disease	4 (2%)	3 (3%)	1 (1%)	.47
Tobacco use	75 (46%)	42 (45%)	33 (47%)	.75
Alcohol abuse	74 (45%)	37 (39%)	37 (53%)	.086

SD, standard deviation; *BMI*, body mass index; *HTN*, hypertension; *COPD*, chronic obstructive pulmonary disease.
Bold values indicate statistical significance ($P < .05$).

postoperatively, of which 5 cases (71%) eventually united. One elected conservative management and failed to unite at the final follow-up. No difference was observed in rate of union after ORIF of open vs. closed fractures (91% vs. 87%, $P = .63$).

Seventy patients (43%) were initially treated nonoperatively, and 58 (83%) of them healed. Five patients had symptomatic fractures beyond 10 weeks and underwent delayed ORIF, and 4 of them achieved secondary union. There were 7 nonunions in the nonoperative group (10%), 3 of which underwent delayed ORIF at mean 48 (24-70) weeks and achieved union. The other 4 declined surgery and failed to unite at the final follow-up. The overall rate of primary fracture union of all patients was 88%, with a trend for higher rate of union after ORIF, which failed to achieve statistical significance (92% vs. 83%, $P = .095$).

Seventeen patients (18%) developed 20 complications (21%) after ORIF including implant failure (6%), iatrogenic radial nerve palsy (5%), deep infection (5%), superficial infection (3%), and painful implants (1%). All iatrogenic nerve injuries affected the radial nerve and were associated with the anterolateral approach to the humerus. There were 16 (17%) total secondary procedures including revision ORIF (n = 7) irrigation and débridement of infection (n = 4), implant removal (n = 2), nerve grafting (n = 2), and amputation (n = 1).

Univariate analysis of possible predictors of nonunion is shown in Table IV. Multivariate logistic regression controlling for confounding variables (age, sex, smoking) demonstrated alcohol abuse (OR: 3.4, 95% CI: 1.0-11.0, $P = .046$) and deep infection (OR: 19.9, 95% CI: 2.6-150.5, $P = .004$) to be predictors of nonunion or symptomatic fracture at 6 weeks. Chronic liver disease demonstrated increased risk (OR: 4.1, 95% CI: 0.8-20.9, $P = .089$).

Discussion

Nonoperative management with functional bracing has been the gold standard for treatment of closed, isolated humeral shaft fractures owing to early studies that reported high union rates (90%-95%), acceptable cosmesis, functional outcome, and cost-effectiveness.[10,22,23] However, successful bracing relies on patient tolerance of bracing and adherence to instructions.[24,28] In series evaluating fractures exclusively treated with surgery, 83%-96% of fractures achieved union.[2,5,7,11,15,26] The aim of our study was to compare the nonoperative and operative groups with respect to patient demographics, injury mechanism, and fracture characteristics, and to compare the rates of nonunion and complications. Secondly, we aimed to develop a model identifying potential predictors of nonunion.

Patients who underwent primary surgery tended to be younger, more frequently male, and with fewer comorbidities. Comparatively, our nonoperative group sustained higher rates of isolated fractures, low-energy falls, and closed injuries, similar to previous reports.[8,10,24,28] Prior epidemiologic studies have demonstrated that most fractures are simple type A fractures and occur in the midshaft.[9,21,29,30] Similarly, most fractures in our study were simple

Table II
Mechanisms of injury and associated injuries

	All (n = 164)	Operative (n = 94)	Nonoperative (n = 70)	*P* value
Mechanism				**<.0001**
Motor vehicle collsion	46 (28%)	**32 (34%)**	**14 (20%)**	
Fall—standing	42 (26%)	**11 (12%)**	**31 (44%)**	
Fall—height	24 (15%)	15 (16%)	9 (13%)	
Gunshot wound	12 (7%)	6 (6%)	6 (9%)	
Motorcycle crash	11 (7%)	**9 (10%)**	**2 (3%)**	
Isolated injury	87 (53%)	**30 (32%)**	**57 (81%)**	**<.0001**
Open fracture	22 (13%)	**22 (23%)**	**0**	**<.0001**
Type 1	3 (14%)	3 (14%)		
Type 2	3 (14%)	3 (14%)		
Type 3A	6 (26%)	6 (26%)		
Type 3B	3 (14%)	3 (14%)		
Type 3C	5 (22%)	5 (22%)		
Primary nerve palsy	40 (24%)	**34 (36%)**	**6 (8.6%)**	**<.0001**
Radial nerve	38 (81%)	27 (79%)	6	
Brachial plexopathy	5 (3%)	5 (15%)	0	
Vascular injury	4 (2%)	4 (4%)	0	

Percentages represent the proportion of patients in that column with a given feature.
Bold values indicate statistical significance ($P < .05$).

Table III
Fracture location and classification

Characteristic (n, %)	All (n = 164)	Operative (n = 94)	Nonoperative (n = 70)	*P* value
Side (% right)	96 (58%)	57 (60%)	39 (55%)	.38
Location				.59
Proximal	48 (29%)	25 (27%)	23 (33%)	
Middle	69 (42%)	39 (41%)	29 (41%)	
Distal	48 (29%)	30 (32%)	18 (26%)	
Fracture pattern (AO/OTA)*				
Simple (type A)	55 (47%)	33 (51%)	22 (43%)	.58
A1	22	10	12	.30
A2	20	15	5	
A3	13	8	5	
Wedge (type B)	31 (27%)	16 (23%)	15 (29%)	
B1	18	7	11	
B2	8	6	2	
B3	6	3	3	
Complex (type C)	31 (26%)	17 (26%)	14 (28%)	
C1	17	8	9	
C2	2	2	0	
C3	11	6	5	

AO/OTA, Arbeitsgemeinschaft für Osteosynthesefragen/Orthopaedic Trauma Association.
Percentages represent the proportion of patients in that column with a given feature.
* 117 patients were classified according to the AO/OTA classification.

patterns located in the midshaft. Comparisons of our operative and nonoperative cohorts showed a relatively similar distribution by the Arbeitsgemeinschaft für Osteosynthesefragen/Orthopaedic Trauma Association fracture classification, and by fracture location: proximal, midshaft, or distal, and consistent with prior work.[16]

Primary fracture union rates were similar in the operative and nonoperative groups (92% vs. 83%, $P = .095$). Repeat analysis limited to closed fractures revealed a similar rate of nonunion after primary ORIF. Our primary fracture union rates are similar to those in prior retrospective studies but lower than the more recent single center randomized trials.[8,12,16,34] Denard et al[8] reported a higher rate of nonunion in the nonoperative vs. operative group (21% vs. 9%, $P = .013$) with no difference in time to union (4.8 months) or elbow range of motion. Similarly, Westrick et al[34] found a higher rate of nonunion in nonoperative patients (23% vs. 10%, $P = .006$) but no difference in time to union. Operative patients were more frequently male, younger (31 vs. 42 years), and had higher rates of multiple injuries and high-energy trauma. A randomized trial of 60 patients found no difference in nonunion (0% operative vs. 6.6% nonoperative) or Disabilities of the Arm, Shoulder and Hand scores (29 vs. 26), but fractures in the operative group united on average 4-5 weeks earlier (13.9 vs. 18.7 weeks). Matsunaga et al[16] found 15% nonunion rate in patients treated in a brace compared with 0% in the operative group in their randomized trial. Two (4%) additional patients converted to ORIF for inability to tolerate the brace. Our findings suggest a low institutional tolerance to delayed union and low threshold to convert to ORIF. Likewise, one recent large multicenter study evaluating modern results of bracing suggested frequent intolerance and noncompliance with bracing and a high rate (29%) of conversion to surgery.[24]

Table IV
Univariate analysis to assess potential risk factors for nonunion

Variable	OR	95% CI	*P* value
Treatment (reference = operative)	**0.4**	**0.2-1.2**	**.11**
Age			
Sex (reference = male)	0.6	0.2-1.4	.22
Comorbidity			
Diabetes	0.83	0.17-3.89	.81
Chronic kidney	0	0	.99
Liver disease	**4.9**	**1.1-22.4**	**.04**
Smoking	**1.9**	**0.7-5.0**	**.18**
Alcohol abuse	**2.53**	**0.9-6.7**	**.063**
Open fracture	1.1	0.3-4.3	.90
Energy of injury (reference = low energy)	0.8	0.3-2.1	.69
Traumatic nerve palsy	1.0	0.4-3.1	.95
Polytrauma (reference = isolated fracture)	1.6	0.6-4.1	.34
Fracture class (AO/OTA) (reference = type C)			.69
A	1.8	0.3-9.4	.50
B	2.1	0.4-12.7	.40
C	Ref	ref	ref
Fracture location (ref. = distal)			
Proximal third	**3.0**	**0.7-12.1**	**.12**
Middle third	2.3	0.6-8.9	.23
Distal third	Ref	Ref	Ref
Deep infection	**12.5**	**1.9-80.4**	**.008**

AO/OTA, Arbeitsgemeinschaft für Osteosynthesefragen/Orthopaedic Trauma Association; *OR*, odds ratio; *CI*, confidence interval.
Covariates in bold were tested in the multivariate logistic regression and excluded due to lack of statistical significance or included to adjust for the confounding variable.

Through univariate analysis, potential predictors of nonunion were identified. Liver disease, smoking, alcohol abuse, and proximal and midshaft fractures were associated with higher risk of nonunion. Cirrhosis, tobacco smoking, and alcohol abuse are known risk factors for nonunion, likely related to associated poor nutrition and dysfunctional microcirculation.[13] In our cohort, multivariate analysis showed liver disease and/or alcohol abuse to remain predictive of nonunion, irrespective of type of treatment.

Despite the trend for higher primary union after operative treatment, risks of complications and secondary procedures must be considered. We noted an 18% complication rate with implant failure (6%), iatrogenic nerve palsy (5%), and deep infection (5%), the most common. Similar rates (1%, 4.8%, 6.3%, respectively) after plate osteosynthesis were reported in a large metanalysis.[19] We report a 21% rate of secondary procedures after ORIF with plate fixation, higher than the 13%-15% rate reported in 2 large studies by Chen et al[6] and Ouyang et al.[19] Secondary procedures remain a concern after fixation. Future cost-effective analysis will be helpful in determining the value of operative vs. nonoperative management.

Our study has several limitations. It is a retrospective study, and a large number of patients were excluded for incomplete records and poor follow-up. Functional data (elbow, shoulder range of motion) were inconsistently recorded in clinic notes and patient-reported outcomes were not collected. Selection bias for type of treatment was also present, in that each surgeon had unique treatment indications and variable tolerance before declaring and intervening for delayed union. Lastly, our regression model is imperfect and is limited due to the low frequency of events (nonunion) limiting the number of covariates, and resulting in wide confidence intervals.

Conclusion

Most humerus shaft fractures unite primarily after operative or nonoperative management. Those treated nonoperatively tended to be older patients with more comorbidity and more isolated humeral shaft fractures after lower energy injury mechanisms. Multivariate adjusted for confounders demonstrated alcohol abuse and chronic liver disease to be predictors of nonunion, regardless of type of treatment. Patients should be counseled about the high risk of nonunion in the presence of underlying risk factors.

Disclaimer

The other authors, their immediate families, and any research foundations with which they are affiliated have not received any financial payments or other benefits from any commercial entity related to the subject of this article.

References

1. Ali E, Griffiths D, Obi N, Tytherleigh-Strong G, Van Rensburg L. Nonoperative treatment of humeral shaft fractures revisited. J Shoulder Elbow Surg 2015;24:210–4. https://doi.org/10.1016/j.jse.2014.05.009.
2. Bell MJ, Beauchamp CG, Kellam JK, McMurtry RY. The results of plating humeral shaft fractures in patients with multiple injuries. The Sunnybrook experience. J Bone Joint Surg Br 1985;67:293–6.
3. Carroll EA, Schweppe M, Langfitt M, Miller AN, Halvorson JJ. Management of humeral shaft fractures. J Am Acad Orthop Surg 2012;20:423–33. https://doi.org/10.5435/JAAOS-20-07-423.
4. Center for Disease Control and Prevention. Alcohol and public health. https://www.cdc.gov/alcohol/fact-sheets/alcohol-use.htm. Accessed 10 June 2020.
5. Chao T-C, Chou W-Y, Chung J-C, Hsu C-J. Humeral shaft fractures treated by dynamic compression plates, Ender nails and interlocking nails. Int Orthop 2005;29:88–91. https://doi.org/10.1007/s00264-004-0620-8.
6. Chen F, Wang Z, Bhattacharyya T. Outcomes of nails versus plates for humeral shaft fractures: a Medicare cohort study. J Orthop Trauma 2013;27:68–72. https://doi.org/10.1097/BOT.0b013e31824a3e66.
7. Demirel M, Turhan E, Dereboy F, Ozturk A. Interlocking nailing of humeral shaft fractures. A retrospective study of 114 patients. Indian J Med Sci 2005;59:436–42. https://doi.org/10.4103/0019-5359.17050.
8. Denard A, Richards JE, Obremskey WT, Tucker MC, Floyd M, Herzog GA. Outcome of nonoperative vs operative treatment of humeral shaft fractures: a retrospective study of 213 patients. Orthopedics 2010;33. https://doi.org/10.3928/01477447-20100625-16.
9. Ekholm R, Adami J, Tidermark J, Hansson K, Tornkvist H, Ponzer S. Fractures of the shaft of the humerus: an epidemiological study of 401 fractures. J Bone Joint Surg Br 2006;88-B:1469–73. https://doi.org/10.1302/0301-620X.88B11.17634.
10. Ekholm R, Tidermark J, Törnkvist H, Adami J, Ponzer S. Outcome after closed functional treatment of humeral shaft fractures. J Orthop Trauma 2006;20:591–6. https://doi.org/10.1097/01.bot.0000246466.01287.04.
11. Heim D, Herkert F, Hess P, Regazzoni P. Surgical treatment of humeral shaft fractures—the Basel experience. J Trauma 1993;35:226–32.
12. Hosseini Khameneh SM, Abbasian M, Abrishamkarzadeh H, Bagheri S, Abdollahimajd F, Safdari F, et al. Humeral shaft fracture: a randomized controlled trial of nonoperative versus operative management (plate fixation). Orthop Res Rev 2019;11:141–7. https://doi.org/10.2147/ORR.S212998.
13. King AR, Moran SL, Steinmann SP. Humeral nonunion. Hand Clin 2007;23:449–56. https://doi.org/10.1016/j.hcl.2007.09.003.
14. Ma J, Xing D, Ma X, Gao F, Wei Q, Jia H, et al. Intramedullary nail versus dynamic compression plate fixation in treating humeral shaft fractures: grading the evidence through a meta-analysis. PLoS One 2013;8:e82075. https://doi.org/10.1371/journal.pone.0082075.
15. Maresca A, Sangiovanni P, Cerbasi S, Politano R, Fantasia R, Commessatti M, et al. Why a surgically treated humeral shaft fracture became a nonunion: review of 11 years in two trauma centers. Musculoskelet Surg 2017;101(Suppl 2):105–12. https://doi.org/10.1007/s12306-017-0509-5.
16. Matsunaga FT, Tamaoki MJS, Matsumoto MH, Netto NA, Faloppa F, Belloti JC. Minimally invasive osteosynthesis with a bridge plate versus a functional brace for humeral shaft fractures: a randomized controlled trial. J Bone Joint Surg Am 2017;99:583–92. https://doi.org/10.2106/JBJS.16.00628.
17. McCormack RG, Brien D, Buckley RE, McKee MD, Powell J, Schemitsch EH. Fixation of fractures of the shaft of the humerus by dynamic compression plate or intramedullary nail. A prospective, randomised trial. J. Bone Joint Surg Br 2000;82:336–9.
18. Meinberg EG, Agel J, Roberts CS, Karam MD, Kellam JF. Fracture and dislocation classification compendium-2018. J Orthop Trauma 2018;32(Suppl 1):S1–170. https://doi.org/10.1097/BOT.0000000000001063.
19. Ouyang H, Xiong J, Xiang P, Cui Z, Chen L, Yu B. Plate versus intramedullary nail fixation in the treatment of humeral shaft fractures: an updated meta-analysis. J Shoulder Elbow Surg 2013;22:387–95. https://doi.org/10.1016/j.jse.2012.06.007.
20. Papasoulis E, Drosos GI, Ververidis AN, Verettas D-A. Functional bracing of humeral shaft fractures. A review of clinical studies. Injury 2010;41:e21–7. https://doi.org/10.1016/j.injury.2009.05.004.
21. Rose SH, Melton LJ, Morrey BF, Ilstrup DM, Riggs BL. Epidemiologic features of humeral fractures. Clin Orthop 1982:24–30.
22. Sarmiento A, Kinman PB, Galvin EG, Schmitt RH, Phillips JG. Functional bracing of fractures of the shaft of the humerus. J Bone Joint Surg Am 1977;59:596–601.
23. Sarmiento A, Zagorski JB, Zych GA, Latta LL, Capps CA. Functional bracing for the treatment of fractures of the humeral diaphysis. J Bone Joint Surg Am 2000;82:478–86.
24. Serrano R, Mir HR, Sagi HC, Horwitz DS, Ketz JP, Kistler BJ, et al. Modern results of functional bracing of humeral shaft fractures: a multicenter retrospective analysis. J Orthop Trauma 2020;34:206–9. https://doi.org/10.1097/BOT.0000000000001666.
25. Singh AK, Arun GR, Narsaria N, Srivastava A. Treatment of non-union of humerus diaphyseal fractures: a prospective study comparing interlocking nail and locking compression plate. Arch Orthop Trauma Surg 2014;134:947–53. https://doi.org/10.1007/s00402-014-1973-0.
26. Singisetti K, Ambedkar M. Nailing versus plating in humerus shaft fractures: a prospective comparative study. Int Orthop 2010;34:571–6. https://doi.org/10.1007/s00264-009-0813-2.
27. Stoltzfus JC. Logistic regression: a brief primer. Acad Emerg Med 2011;18:1099–104. https://doi.org/10.1111/j.1553-2712.2011.01185.x.
28. Toivanen JAK, Nieminen J, Laine H-J, Honkonen SE, Järvinen MJ. Functional treatment of closed humeral shaft fractures. Int Orthop 2005;29:10–3. https://doi.org/10.1007/s00264-004-0612-8.
29. Tsai C-H, Fong Y-C, Chen Y-H, Hsu C-J, Chang C-H, Hsu H-C. The epidemiology of traumatic humeral shaft fractures in Taiwan. Int Orthop 2009;33:463–7. https://doi.org/10.1007/s00264-008-0537-8.
30. Tytherleigh-Strong G, Walls N, McQueen MM. The epidemiology of humeral shaft fractures. J Bone Joint Surg Br 1998;80:249–53.
31. Updegrove GF, Mourad W, Abboud JA. Humeral shaft fractures. J Shoulder Elbow Surg 2018;27:e87–97. https://doi.org/10.1016/j.jse.2017.10.028.
32. U.S. Department of Health and Human Services and U.S. Department of Agriculture. 2015-2020 Dietary Guidelines for Americans. 8th ed. https://health.gov/our-work/food-nutrition/2015-2020-dietary-guidelines. Accessed 10 June 2020.
33. Walker M, Palumbo B, Badman B, Brooks J, Van Gelderen J, Mighell M. Humeral shaft fractures: a review. J Shoulder Elbow Surg 2011;20:833–44. https://doi.org/10.1016/j.jse.2010.11.030.
34. Westrick E, Hamilton B, Toogood P, Henley B, Firoozabadi R. Humeral shaft fractures: results of operative and non-operative treatment. Int Orthop 2017;41:385–95. https://doi.org/10.1007/s00264-016-3210-7.