Risk factors for nonunion after traumatic humeral shaft fractures in adults

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A R T I C L E   I N F O

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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 debridement 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 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%).

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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. 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.

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.14 Secondary outcome measures included postoperative complications rates including iatrogenic nerve palsy, deep infection requiring return to operating room for debridement, 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. x2 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. 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 (52% vs. 36%, P = .013), and a trend was noted for those with a history of dependence on 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 debridement and ORIF. Primary nerve palsy was found in 24% of patients, with radial nerve (8%) the most commonly injured nerve. Fractures demonstrated a relatively even distribution of proximal-third (29%), middle-third (42%), and distal-third (28%) 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.

Figure 1 Inclusion and exclusion criteria used to identify the final 164 patients included in the study.
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 debridement 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. However, successful bracing relies on patient tolerance of bracing and adherence to instructions. In series evaluating fractures exclusively treated with surgery, 83%-96% of fractures achieved union. 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. Prior epidemiologic studies have demonstrated that most fractures are simple type A fractures and occur in the midshaft. Similarly, most fractures in our study were simple

### 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 (15.9)         | 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 (75%)            | 5 (58%)                  | 6 (95%)                   | .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 (\( P < .05 \)).

### Table II
Mechanisms of injury and associated injuries

| Mechanism                        | All (\( n = 164 \)) | Operative (\( n = 94 \)) | Nonoperative (\( n = 70 \)) | \( P \) value |
|----------------------------------|---------------------|--------------------------|----------------------------|-------------|
| Motor vehicle collision          | 46 (28%)            | 32 (34%)                 | 14 (20%)                   | <.0001      |
| Fall—standing                    | 42 (26%)            | 11 (12%)                 | 31 (44%)                   | <.0001      |
| Fall—height                      | 24 (15%)            | 15 (16%)                 | 9 (13%)                    | <.0001      |
| Gunshot wound                    | 12 (7%)             | 6 (6%)                   | 6 (9%)                     | <.0001      |
| Motorcycle crash                 | 11 (7%)             | 9 (10%)                  | 2 (3%)                     | <.0001      |
| Isolated injury                  | 87 (53%)            | 30 (32%)                 | 57 (81%)                   | <.0001      |
| Open fracture                    | 22 (13%)            | 22 (23%)                 | 0                          | <.0001      |
| Type 1                           | 3 (14%)             | 3 (14%)                  | 0                          | <.0001      |
| Type 2                           | 3 (14%)             | 3 (14%)                  | 0                          | <.0001      |
| Type 3A                          | 6 (26%)             | 6 (26%)                  | 0                          | <.0001      |
| Type 3B                          | 3 (14%)             | 3 (14%)                  | 0                          | <.0001      |
| Type 3C                          | 5 (22%)             | 5 (22%)                  | 0                          | <.0001      |
| Primary nerve palsy              | 40 (24%)            | 34 (36%)                 | 6 (8.6%)                   | <.0001      |
| Radial nerve                     | 38 (21%)            | 27 (79%)                 | 1 (1%)                     | .004        |
| Brachial plexopathy              | 5 (3%)              | 5 (15%)                  | 0                          | .004        |
| Vascular injury                  | 4 (2%)              | 4 (4%)                   | 0                          | .004        |

Percentages represent the proportion of patients in that column with a given feature. Bold values indicate statistical significance (\( P < .05 \)).
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 al8 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 al34 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 al16 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

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 metaanalysis.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 al15 and Ouyang et al.10 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

| Characteristic (n, %) | All (n = 164) | Operative (n = 94) | Nonoperative (n = 70) | P value |
|----------------------|--------------|-------------------|----------------------|---------|
| Side (% right)       |              |                   |                      |         |
| Proximal             | 48 (29%)     | 25 (27%)          | 23 (33%)             | .59     |
| Middle               | 69 (42%)     | 39 (41%)          | 30 (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                    |         |

| Variable | OR   | 95% CI | P value |
|----------|------|--------|---------|
| Treatment (reference = operative) | 0.4  | 0.2-1.2 | .11     |
| Age      | 0.6  | 0.2-1.4 | .22     |
| Sex (reference = male)            |      |        |         |
| 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) | 1.8  | 0.3-9.4 | .50     |
| 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.
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.

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