

Distinct clinical phenotypes of upper and lower extremity long bone nonunion: upper extremity nonunion is associated with lower infection and reconstructive burden

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Abstract

Introduction: Long bone nonunion is conventionally treated as a uniform disease entity regardless of anatomical location. However, upper and lower extremities differ fundamentally in biomechanics, soft tissue envelope, vascularity, and open fracture risk. We hypothesized that these differences give rise to distinct clinical nonunion phenotypes.

Methods: Retrospective cohort study of 213 consecutive long bone nonunions treated at a Level 1 trauma center (2007–2018). Patients were stratified by anatomical location into upper extremity (UE, n = 74, 34.7%) and lower extremity (LE, n = 139, 65.3%) nonunions. Groups were compared regarding demographics, comorbidities, fracture characteristics, infection rates, operative burden, laboratory parameters, and treatment strategies. Multivariate logistic regression identified independent predictors of septic nonunion and high revision burden (≥ 3 operations).

Results: Lower extremity nonunion demonstrated a markedly higher infection and reconstructive burden. Septic nonunion was 3.4 times more frequent in the LE group (27.3% vs. 8.1%; $p = 0.002$). Open fractures were significantly more common (30.9% vs. 6.8%; $p < 0.001$). The LE group required significantly more revision and follow-up operations (3.3 ± 5.0 vs. 1.4 ± 1.1 ; $p < 0.001$), had a higher rate of two-stage procedures (27.3% vs. 4.1%; $p < 0.001$), and more frequently needed BMP augmentation (12.9% vs. 1.4%; $p = 0.004$). Despite these differences, demographics, BMI, comorbidity burden, leukocyte counts, and implant loosening rates did not differ. On multivariate analysis, lower extremity location was an independent predictor of septic nonunion (OR 2.80, 95% CI 1.04–7.54; $p = 0.042$), alongside open fracture (OR 3.01; $p = 0.021$) and BMI (OR 1.07; $p = 0.011$).

Conclusion: Upper and lower extremity nonunions represent distinct clinical phenotypes. Lower extremity nonunion is characterized by a substantially higher infection-driven reconstructive burden, likely reflecting the biomechanical demands, limited soft tissue coverage, and greater open fracture risk inherent to the lower limb. These findings support anatomically stratified risk assessment and treatment planning.

Introduction

Long bone nonunion — defined as failure of fracture healing at a minimum of six months — remains a significant complication in orthopedic trauma surgery, affecting approximately 5–10% of all long bone fractures [1, 2]. Nonunion imposes a substantial burden on patients through pain, functional impairment, repeated surgery, and prolonged inability to work, while generating considerable healthcare costs estimated at over €25,000 per case for tibial nonunion alone [3, 4].

Current literature and clinical practice largely treat nonunion as a uniform disease entity, classified primarily by morphological criteria (atrophic vs. hypertrophic) and by the presence or absence of infection [5, 6]. Treatment algorithms — including the widely adopted "diamond concept" combining mechanical stability, osteoconduction, osteoinduction, and osteogenic cells — are applied across

anatomical locations without systematic differentiation [7]. Risk factor analyses have focused predominantly on patient-level variables such as smoking, diabetes, age, and nutritional status, or on injury-level variables such as fracture pattern, soft tissue damage, and initial fixation method [8, 9].

However, the upper and lower extremities differ fundamentally in ways that are likely to influence fracture healing and nonunion development. The lower extremity is subject to substantial axial loading forces during weight-bearing, placing high mechanical demands on fracture fixation and callus maturation [10]. The tibial diaphysis — the single most common site of nonunion — is characterized by a limited soft tissue envelope, a predominantly single-vessel blood supply (anterior tibial artery), and a subcutaneous anteromedial border that is particularly vulnerable to open fracture and soft tissue compromise [11, 12]. In contrast, the upper extremity generally benefits from more robust circumferential soft tissue coverage, a richer vascular supply, and the absence of weight-bearing demands, potentially creating a more favorable biological environment for fracture healing [13].

These anatomical differences may have important consequences for the pathophysiology of nonunion. Open fractures — a well-established risk factor for both nonunion and fracture-related infection (FRI) — occur far more frequently in the lower extremity [14, 15]. Fracture-related infection, now recognized as a distinct clinical entity with specific diagnostic criteria by the FRI Consensus Group [16, 17], is the primary driver of complex, staged reconstructive procedures and prolonged treatment courses [18]. If lower extremity nonunion is indeed more frequently associated with infection and reconstructive complexity, this distinction has direct implications for risk stratification, patient counseling, infection surveillance, and resource allocation.

Despite these considerations, comparative analyses between upper and lower extremity nonunion remain remarkably limited. Most existing studies focus on specific bones (tibial nonunion, humeral nonunion), specific pathologies (septic vs. aseptic), or isolated risk factors, without systematically comparing the clinical phenotype of nonunion across anatomical regions [19–21].

The aim of this study was to compare the clinical characteristics, infection burden, operative history, and reconstructive complexity of upper versus lower extremity long bone nonunion in a large consecutive cohort, and to explore whether anatomical location is associated with distinct nonunion phenotypes.

Materials and Methods

This retrospective cohort study was conducted at a Level 1 trauma center. All consecutive patients treated for long bone nonunion between January 2007 and April 2018 were identified using ICD-10 code M84.1. Data were extracted from a prospectively maintained institutional database. Nonunion was defined as failure of fracture healing at a minimum of six months following initial injury or fixation, confirmed by clinical assessment and imaging (persistent fracture gap, absent bridging callus on radiographs or computed tomography) [5]. Patients were classified based on the AO/OTA fracture classification into upper extremity (AO regions 1 and 2: humerus, radius, ulna) and lower extremity (AO regions 3 and 4: femur, tibia, fibula, ankle) nonunions. The variables analyzed included demographic and

anthropometric characteristics, such as age at fracture, sex, BMI, ASA physical status, and insurance type (workers' compensation, statutory, or private). Comorbidity profile includes the total number of comorbidities, medication count, individual comorbidities such as cardiovascular disease, diabetes, osteoporosis, nicotine use, pulmonary, thyroid, renal, psychiatric, and neurological diseases, as well as allergies. The fracture and injury characteristics included open versus closed fracture, Gustilo–Anderson grade, and monotrauma versus polytrauma. The nonunion was characterized morphologically as either atrophic or hypertrophic, classified as septic or aseptic, and assessed for mechanical implant failure, including implant loosening.

The operative history included the initial osteosynthesis technique, time from fixation to revision (in months), number of prior operations, number of revision and follow-up operations, and whether a single-stage or two-stage approach was used.

Laboratory parameters included the pre-operative leukocyte count, C-reactive protein (CRP), and creatinine levels. Treatment-related variables included the bone grafting strategy (autologous cancellous bone, bone morphogenetic protein [BMP], bone substitute, or none), the type of the first revision procedure, and CT imaging findings.

Continuous variables were expressed as mean $\pm$ standard deviation (SD) or median with interquartile range (IQR), as appropriate, while categorical variables were presented as frequencies and percentages (n [%]). Between-group comparisons were performed using the Mann–Whitney U test for continuous variables and the chi-square test or Fisher's exact test for categorical variables, as appropriate. Multivariable logistic regression analyses were conducted to identify independent predictors of septic nonunion and high revision burden, defined as ≥ 3 operations, with results reported as odds ratios (ORs) and 95% confidence intervals (CIs). A two-sided p-value < 0.05 was considered statistically significant. All statistical analyses were performed using Python version 3.12 with the SciPy and statsmodels libraries.

Results

Demographics and comorbidities

Of 213 long bone nonunions, 74 (34.7%) involved the upper extremity and 139 (65.3%) the lower extremity. Within the upper extremity, the most common sites were the forearm diaphysis (n = 26, 35.1%), proximal forearm (n = 16, 21.6%), humeral diaphysis (n = 14, 18.9%), and proximal humerus (n = 11, 14.9%). Within the lower extremity, the tibial diaphysis (n = 29, 20.9%), femoral diaphysis (n = 25, 18.0%), proximal femur (n = 23, 16.5%), distal tibia (n = 19, 13.7%), and ankle (n = 18, 12.9%) were most frequent (Fig. 1).

No significant differences were observed between groups regarding age (49.1 ± 16.9 vs. 53.2 ± 17.3 years; p = 0.122), sex distribution (59.5% vs. 60.4% male; p = 1.000), BMI (27.9 ± 6.4 vs. 28.3 ± 6.9 kg/m²; p = 0.777), or ASA classification (ASA $\geq$ III: 21.6% vs. 25.2%; p = 0.681). Comorbidity burden (2.1 ± 1.7 vs.

2.2 ± 1.7; p = 0.379) and medication count (2.4 ± 2.2 vs. 2.9 ± 2.7; p = 0.213) were comparable. Cardiovascular disease (50.0% vs. 54.7%; p = 0.612), diabetes (13.5% vs. 10.8%; p = 0.716), osteoporosis (9.5% vs. 10.1%; p = 1.000), and nicotine use (45.9% vs. 35.3%; p = 0.169) did not differ significantly between groups (Table 1).

Variable	Upper (n = 74)	Lower (n = 139)	p-value	Test
Demographics				
Age, years, mean ± SD	49.1 ± 16.9	53.2 ± 17.3	0.122	MWU
Male sex, n (%)	44 (59.5)	84 (60.4)	1.000	Fisher
BMI, kg/m ² , mean ± SD	27.9 ± 6.4	28.3 ± 6.9	0.777	MWU
ASA score, mean ± SD	2.1 ± 0.5	2.2 ± 0.6	0.412	MWU
ASA ≥ III, n (%)	16 (21.6)	35 (25.2)	0.681	χ ²
Workers' compensation, n (%)	12 (16.2)	18 (12.9)	0.656	Fisher
Comorbidities				
Comorbidity count, mean ± SD	2.1 ± 1.7	2.2 ± 1.7	0.379	MWU
Medication count, mean ± SD	2.4 ± 2.2	2.9 ± 2.7	0.213	MWU
Cardiovascular disease, n (%)	37 (50.0)	76 (54.7)	0.612	χ ²
Diabetes / metabolic, n (%)	10 (13.5)	15 (10.8)	0.716	Fisher
Nicotine use, n (%)	34 (45.9)	49 (35.3)	0.169	χ ²
Osteoporosis, n (%)	7 (9.5)	14 (10.1)	1.000	Fisher
Pulmonary disease, n (%)	8 (10.8)	27 (19.4)	0.155	Fisher
Thyroid disease, n (%)	11 (14.9)	37 (26.6)	0.075	χ ²
Renal insufficiency, n (%)	8 (10.8)	11 (7.9)	0.650	Fisher

MWU = Mann–Whitney U test. No statistically significant differences in demographics or comorbidities.

Table 1. Demographics and comorbidity profile by extremity

Fracture characteristics, operative burden and laboratory values

Open fractures were dramatically more common in the lower extremity (30.9% vs. 6.8%; p < 0.001). This represents a 4.5-fold difference in open fracture rate. Polytrauma was numerically more frequent in the LE group (26.6% vs. 17.6%) but did not reach statistical significance (p = 0.189). Septic nonunion was 3.4 times more prevalent in the lower extremity (27.3% vs. 8.1%; p = 0.002). Atrophic nonunion morphology

was similarly distributed (35.3% vs. 41.9%; $p = 0.421$). Implant loosening did not differ between groups (29.5% vs. 39.2%; $p = 0.200$).

The lower extremity group demonstrated a significantly higher operative burden across multiple parameters. Prior operations before nonunion revision were more numerous (1.9 ± 1.4 vs. 1.4 ± 1.0 ; $p = 0.009$). The total number of revision and follow-up operations was more than double in the LE group (3.3 ± 5.0 vs. 1.4 ± 1.1 ; $p < 0.001$). The rate of high revision burden (≥ 3 operations) was nearly three times higher (26.6% vs. 9.5%; $p = 0.006$). Most strikingly, two-stage procedures were performed in 27.3% of LE cases compared to only 4.1% of UE cases ($p < 0.001$) – a 6.7-fold difference (Fig. 2)

Leukocyte counts were virtually identical (7.6 ± 2.3 vs. $7.7 \pm 2.9 \times 10^9/L$; $p = 0.868$). CRP was numerically higher in the LE group (18.5 ± 35.0 vs. 10.5 ± 17.6 mg/L), though this did not reach significance ($p = 0.137$). Creatinine showed a trend toward higher values in the UE group (1.1 ± 1.3 vs. 0.9 ± 0.5 mg/dL; $p = 0.056$) (Table 2).

Table 2
Fracture Characteristics, Nonunion Features, and Operative Burden

Variable	Upper (n = 74)	Lower (n = 139)	p-value	Test
Fracture characteristics				
Open fracture, n (%)	5 (6.8)	43 (30.9)	< 0.001	Fisher
Polytrauma, n (%)	13 (17.6)	37 (26.6)	0.189	χ^2
Nonunion characteristics				
Atrophic morphology, n (%)	31 (41.9)	49 (35.3)	0.421	χ^2
Septic nonunion, n (%)	6 (8.1)	38 (27.3)	0.002	Fisher
Implant loosening, n (%)	29 (39.2)	41 (29.5)	0.200	χ^2
Operative burden				
Time to revision, months, mean $\pm$ SD	12.4 $\pm$ 27.3	11.7 $\pm$ 15.0	0.327	MWU
Prior operations, mean $\pm$ SD	1.4 $\pm$ 1.0	1.9 $\pm$ 1.4	0.009	MWU
Revision + follow-up ops, mean $\pm$ SD	1.4 $\pm$ 1.1	3.3 $\pm$ 5.0	< 0.001	MWU
High revision burden (≥ 3 ops), n (%)	7 (9.5)	37 (26.6)	0.006	Fisher
Two-stage procedure, n (%)	3 (4.1)	38 (27.3)	< 0.001	Fisher
Laboratory values				
CRP, mg/L, mean $\pm$ SD	10.5 $\pm$ 17.6	18.5 $\pm$ 35.0	0.137	MWU
Leukocytes, $\times 10^9$ /L, mean $\pm$ SD	7.7 $\pm$ 2.9	7.6 $\pm$ 2.3	0.868	MWU
Creatinine, mg/dL, mean $\pm$ SD	1.1 $\pm$ 1.3	0.9 $\pm$ 0.5	0.056	MWU

Treatment strategies

Significant differences in initial fixation reflected anatomical considerations. Plate fixation was more common in the UE group (66.2% vs. 43.2%; $p = 0.002$), while intramedullary nailing predominated in the LE group (33.8% vs. 13.5%; $p = 0.003$). Screw fixation was more frequently the index procedure in LE nonunions (12.2% vs. 2.7%; $p = 0.022$).

At revision, autologous cancellous bone grafting was used more frequently in UE nonunions (58.1% vs. 36.7%; $p = 0.004$), while BMP augmentation was almost exclusively used in LE cases (12.9% vs. 1.4%; $p = 0.004$) (Table 3).

Table 3
Treatment Strategies by Extremity

Variable	Upper (n = 74)	Lower (n = 139)	p-value
Initial fixation			
Plate osteosynthesis, n (%)	49 (66.2)	60 (43.2)	0.002
Intramedullary nail, n (%)	10 (13.5)	47 (33.8)	0.003
Screw fixation, n (%)	2 (2.7)	17 (12.2)	0.022
Conservative, n (%)	9 (12.2)	8 (5.8)	0.168
Bone grafting at revision			
Autologous cancellous bone, n (%)	43 (58.1)	51 (36.7)	0.004
BMP augmentation, n (%)	1 (1.4)	18 (12.9)	0.004
No bone grafting, n (%)	25 (33.8)	62 (44.6)	0.167

Multivariate analysis

Model 1 — Predictors of septic nonunion: Lower extremity location was an independent predictor of septic nonunion (OR 2.80, 95% CI 1.04–7.54; $p = 0.042$), alongside open fracture (OR 3.01, 95% CI 1.18–7.64; $p = 0.021$), BMI (OR 1.07 per kg/m^2 , 95% CI 1.02–1.13; $p = 0.011$), and number of prior operations (OR 1.34, 95% CI 1.00–1.78; $p = 0.047$). Nicotine use and age were not independently associated. Model fit was adequate (pseudo- $R^2=0.171$; LR $p < 0.001$). (Fig. 3A)

Model 2 — Predictors of high revision burden (≥ 3 operations): Septic nonunion was overwhelmingly the strongest predictor (OR 22.50, 95% CI 8.15–62.14; $p < 0.001$), followed by BMI (OR 1.14, 95% CI 1.06–1.23; $p < 0.001$). Lower extremity location showed a trend toward association (OR 2.34, 95% CI 0.72–7.54; $p = 0.156$) but did not reach significance after adjustment for infection status. Model fit was strong (pseudo- $R^2=0.403$; LR $p < 0.001$). (Fig. 3B)

Discussion

This study demonstrates that upper and lower extremity long bone nonunions represent distinct clinical phenotypes rather than a uniform disease entity. Lower extremity nonunion is characterized by a markedly higher infection and reconstructive burden — with 3.4 times the septic nonunion rate, more than double the revision operations, and nearly seven times the two-stage procedure rate — despite comparable demographics, comorbidity profiles, and systemic inflammatory markers. These differences appear to be driven primarily by the substantially higher open fracture rate in the lower extremity and the anatomical vulnerability of lower limb structures.

The lower extremity phenotype: an infection-driven, high-complexity entity

The lower extremity phenotype in our cohort was defined by three interlinked features: open fractures (30.9% vs. 6.8%), septic nonunion (27.3% vs. 8.1%), and high reconstructive complexity (two-stage procedures 27.3% vs. 4.1%). This triad reflects a well-established pathophysiological cascade. Open fractures create the conditions for contamination and biofilm formation on implant surfaces [16, 22]. The tibial diaphysis — the single most frequent site in our LE cohort — is particularly vulnerable due to its subcutaneous anteromedial surface, single dominant nutrient artery, and limited surrounding muscle envelope that would otherwise provide vascular reserve and infection containment [11, 23]. The 4.5-fold difference in open fracture rate between extremities observed in our cohort is consistent with epidemiological data. Court-Brown and Caesar [24] reported that tibial shaft fractures have the highest open fracture rate of any long bone, while humeral and forearm fractures are open in fewer than 5% of cases. This anatomical predisposition translates directly into infection risk: Metsemakers et al. [17] identified open fracture as the most consistent risk factor for FRI across multiple studies, and our multivariate analysis confirmed open fracture as the second strongest independent predictor of septic nonunion (OR 3.01) after lower extremity location itself (OR 2.80). The finding that septic nonunion was the overwhelming driver of high revision burden (OR 22.50) is consistent with the work of Bezstarosti et al. [18], who demonstrated that fracture-related infection is the primary determinant of prolonged, multi-stage treatment courses. Importantly, lower extremity location lost its independent association with high revision burden after adjustment for infection (OR 2.34, $p = 0.156$), suggesting that the relationship between anatomical location and operative complexity is largely mediated through infection.

The upper extremity phenotype: a lower-complexity entity

The upper extremity phenotype presented as a fundamentally different clinical entity. With a septic nonunion rate of only 8.1%, an open fracture rate of 6.8%, and a two-stage procedure rate of 4.1%, UE nonunion appears to arise predominantly through aseptic, mechanically driven pathways. The higher rate of plate fixation (66.2%) and the lower rate of intramedullary nailing (13.5%) reflect the anatomical constraints of upper extremity fixation and may contribute to the different nonunion profile, as plate fixation preserves periosteal biology more selectively depending on technique [25]. The observation that autologous bone grafting was more frequently applied in UE nonunion (58.1% vs. 36.7%) while BMP augmentation was almost exclusively used in the LE group (12.9% vs. 1.4%) suggests that treatment philosophy already differs between extremities in clinical practice — even in the absence of formalized anatomically stratified algorithms. The higher BMP use in LE nonunion may reflect the greater biological challenge of achieving union in weight-bearing bones with compromised soft tissue and vascularity, consistent with evidence supporting BMP-2 and BMP-7 efficacy in critical-sized defects and complex tibial nonunion [26, 27].

The absence of baseline differences — a controlled natural experiment

A striking aspect of our findings is the near-complete absence of demographic and comorbidity differences between groups. Age, sex, BMI, ASA classification, comorbidity count, medication burden, and all individual comorbidities including nicotine use, cardiovascular disease, diabetes, osteoporosis,

and renal impairment were statistically indistinguishable between UE and LE nonunion. Even leukocyte counts, a crude systemic inflammatory marker, were identical. This homogeneity of baseline characteristics strengthens the interpretation that the observed differences in infection burden and operative complexity are driven by anatomical factors rather than patient-level confounders. The comparable nicotine use between groups (45.9% vs. 35.3%) is particularly noteworthy given the overall smoking rate of approximately 39% in the cohort — nearly double the general German population rate [28] — and the well-established role of smoking in impairing fracture healing [29, 30]. The fact that nicotine use was not higher in the LE group suggests that smoking contributes to nonunion risk across both extremities and does not preferentially drive the lower extremity phenotype.

CRP and the limitations of systemic inflammatory markers

CRP was numerically elevated in the LE group (18.5 vs. 10.5 mg/L) but did not reach statistical significance ($p = 0.137$). This finding is clinically relevant because it illustrates the well-documented limitation of CRP as a diagnostic marker for fracture-related infection [31, 32]. Despite a 3.4-fold higher septic nonunion rate, the difference in systemic inflammatory markers was modest and non-significant — underscoring the need for local diagnostic tools (tissue cultures, sonication, histopathology) rather than reliance on serum markers for the diagnosis of implant-associated infection.

Clinical Implications

These findings support several clinical recommendations.

First, anatomical location should be incorporated into nonunion risk stratification. Lower extremity fractures — particularly open tibial fractures — warrant heightened vigilance for infection-related nonunion, earlier microbiological workup, and proactive discussion with patients regarding the possibility of staged reconstruction. Second, infection surveillance protocols may need to be anatomically differentiated. In our cohort, over one-quarter of LE nonunions were septic, supporting a low threshold for tissue sampling and implant sonication at the time of revision surgery for lower extremity cases [16, 33]. Third, resource allocation and patient counseling should reflect the anatomical phenotype. Lower extremity nonunion patients should be counseled regarding the higher likelihood of multiple procedures, prolonged treatment courses, and staged surgical management, while upper extremity cases generally follow a less complex trajectory. Fourth, the near-exclusive use of BMP augmentation in lower extremity nonunion in our cohort, combined with the higher autologous bone grafting rate in the upper extremity, suggests that treatment algorithms already implicitly recognize anatomical differences. Formalizing these distinctions through evidence-based, anatomically stratified protocols may further improve outcomes [7, 34].

Integration with existing frameworks

Our findings complement the "diamond concept" of Giannoudis et al. [7] by adding an anatomical dimension. The biomechanical pillar of the diamond is fundamentally different between extremities —

the upper extremity benefits from non-weight-bearing biology, while the lower extremity must achieve union under mechanical load. The vascular and soft tissue components differ inherently by anatomical region. Future refinements of the diamond concept may benefit from explicitly incorporating anatomical location as a modifying variable.

Our data also connect to the emerging recognition that nonunion is not a single disease but a heterogeneous clinical entity arising through multiple pathways [35]. We have recently shown that fragility-associated and trauma-associated nonunions represent distinct phenotypes [reference to companion paper]. The present analysis adds a complementary anatomical dimension, demonstrating that even within the trauma-associated pathway, the clinical phenotype varies substantially by extremity.

Limitations

This study has several limitations. First, the retrospective single-center design introduces potential information and selection bias. Second, the sample size, while adequate for the primary comparison, limits the power of subgroup analyses within extremity groups (e.g., infected tibial vs. infected femoral nonunion). Third, outcome data (union rates, functional scores) were not available. Fourth, the classification into upper and lower extremity is anatomically broad; future studies should evaluate differences at the level of individual bones. Fifth, open fracture classification (Gustilo grade) was incompletely documented, limiting subgroup analysis. Sixth, the non-significant trend in CRP may reflect a type II error given the sample size and variance of CRP values.

Conclusions

Upper and lower extremity long bone nonunions represent distinct clinical phenotypes. Lower extremity nonunion is characterized by a substantially higher infection burden (3.4-fold), operative complexity (2.4-fold revision operations), and two-stage procedure rate (6.7-fold), driven primarily by the dramatically higher open fracture rate inherent to the lower limb. Upper extremity nonunion presents as a comparatively lower-complexity entity with a predominantly aseptic, mechanically driven profile. These findings support the incorporation of anatomical location into nonunion risk stratification, infection surveillance protocols, and treatment algorithms.

Declarations

Author Contribution

All authors contributed equally to the conception and design of the study, data collection and analysis, interpretation of the results, and preparation of the manuscript. All authors contributed to the revision of the manuscript, approved the final version, and agree to be accountable for all aspects of the work.

Data Availability

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Figures

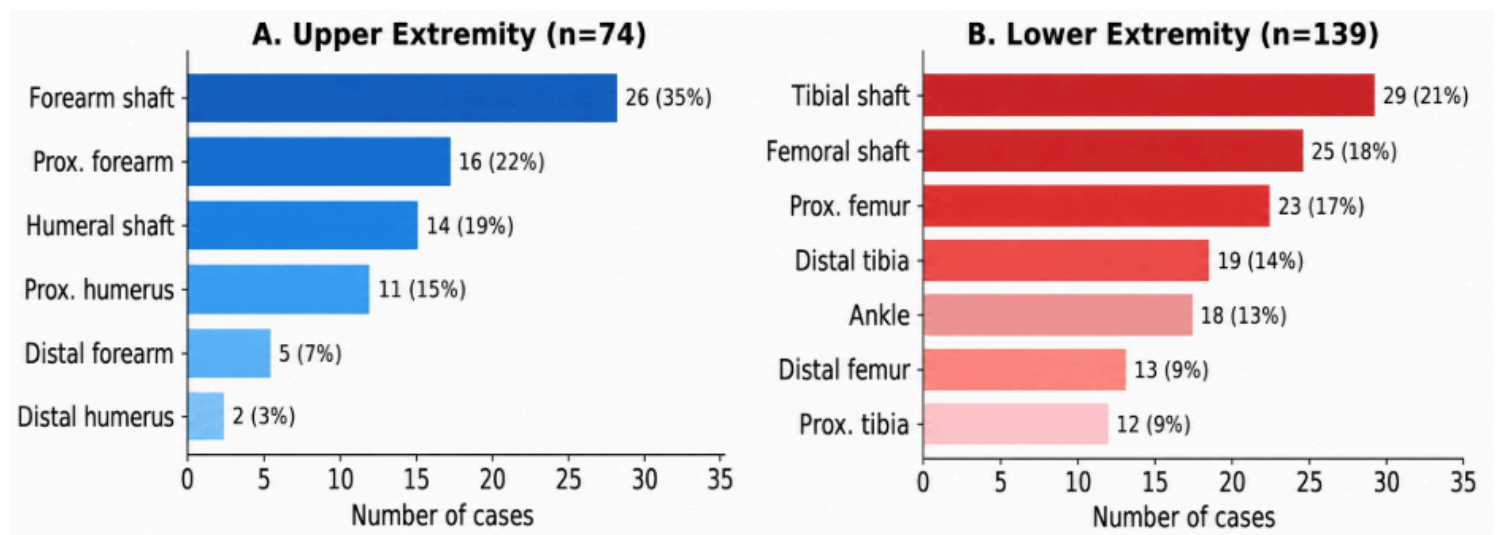


Figure 1

Anatomical distribution of nonunion sites. (A) Upper extremity (n=74): forearm shaft fractures predominate. (B) Lower extremity (n=139): tibial shaft, femoral shaft, and proximal femur are the most common sites.

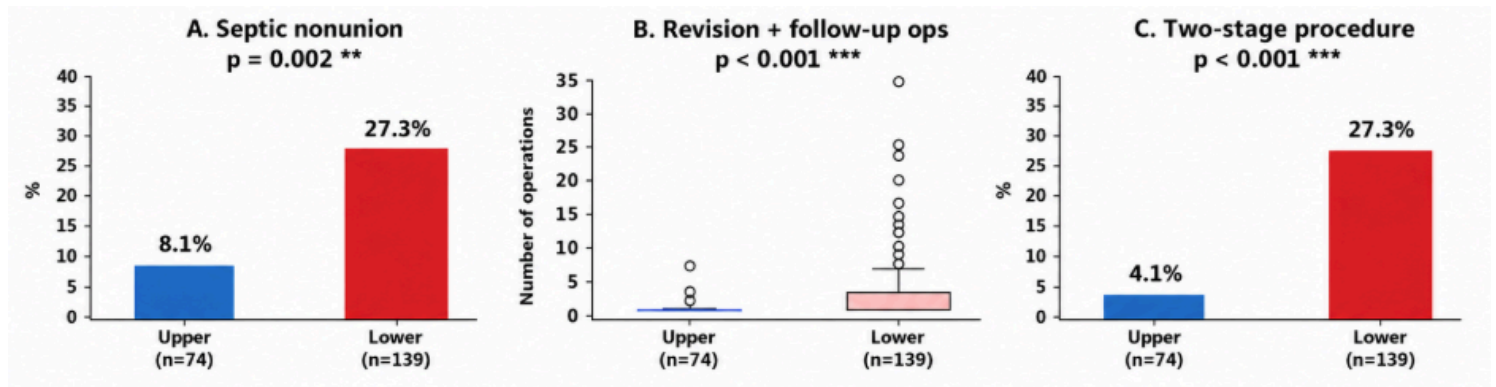


Figure 2

Infection and operative burden by extremity. (A) Septic nonunion rate, (B) revision and follow-up operations (box plot), (C) two-stage procedure rate. All parameters are significantly higher in lower extremity nonunion.

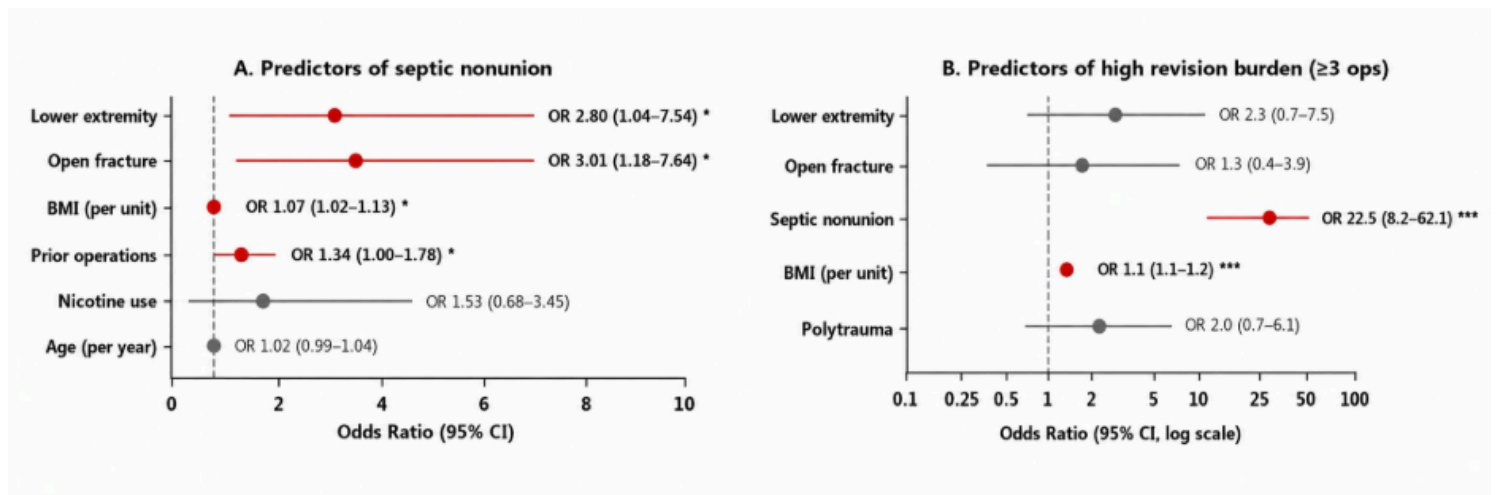


Figure 3

Multivariate logistic regression results. (A) Predictors of septic nonunion: lower extremity location is an independent predictor (OR 2.80). (B) Predictors of high revision burden: septic nonunion dominates (OR 22.50); lower extremity shows a trend (OR 2.34, p=0.156) that loses significance after adjustment for infection.