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Humeral shaft periprosthetic fractures: Fracture patterns differ between short and standard-length arthroplasty stems

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A R T I C L E I N F O

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A B S T R A C T

Introduction: There have been no published studies evaluating the impact of humeral stem length on humeral shaft periprosthetic fractures. We sought evaluate the differences in fracture patterns between periprosthetic fractures around a short stem and standard stem humeral implants.

Materials and methods: This is a retrospective cohort study. Patients sustaining a humeral shaft periprosthetic fracture around shoulder arthroplasty implants from December 2011 to January 2021 were identified using ICD-9/10 codes. Three upper extremity trained surgeons evaluated all radiographs assessing fracture location and configuration, as well as signs of stem stability before and after the fracture. They classified the fractures based on two classification schemes: Wright & Cofield, and the Unified Classification System (UCS), and they recorded their recommended treatment for each case based on fracture pattens and implant stability.

Results: 76 patients with periprosthetic humeral shaft fractures were identified and divided into two groups: short stem (n=18) and standard stem (n=58). Patients with a short stem were more likely to be classified as having an unstable prosthesis after fracture (67% versus 33%, p=0.01). Additionally, the proposed plan for treatment was different between the two groups (p=0.004): more patients in the standard stem group were recommended open reduction internal fixation (50% vs. 33%) or non-operative treatment (17% vs. 0%), and more patients in the short stem group were recommended revision arthroplasty (50% vs. 29%).

Conclusion: Patients sustaining a periprosthetic fracture around a short implant may be more likely to have an unstable prosthesis compared to a standard stem, which may have an impact on treatment options.

Level of Evidence: Prognosis Study, Level III

Introduction

The rate of shoulder arthroplasty procedures has increased significantly in the past twenty years. There was a 147% increase in shoulder arthroplasty procedures from 1998-2008, and further increases of 164% in reverse shoulder arthroplasty (RSA) and 32% in total shoulder arthroplasty (TSA) procedures from 2012-2017 [1,2]. This is in part due to the expanded indications for RSA, as well as the aging population with an increasing incidence of fragility fractures [2–4]. As a result, periprosthetic humerus fractures are becoming more common [5]. Current literature reports that the prevalence of both intraoperative and post-operative periprosthetic humerus fractures ranges from 3.3% to 3.5% in RSA [6–8] and 0.6% to 2.8% in TSA [6,9–11].

Treatment options for periprosthetic humerus fractures include revision arthroplasty if the stem is loose, or open reduction and internal fixation if there is adequate bone stock with a well-fixed component. The use of cortical strut allografts has been shown to be helpful in decreasing the risk of nonunion [12].

Several different published classification systems for periprosthetic humerus fractures describe the location of the fracture around the humeral stem [13–18]. Each of these previously described classification systems are based on a limited number of cases. The Wright & Cofield classification system was the first to be described, and it remains the most commonly used in published reports [13]. A more recent classification system, the Unified Classification System (UCS), attempts to capture more relevant information that can help direct treatment planning [14]. However, this system has not yet gained wide-spread use.

Publications discussing periprosthetic fractures in short-stem

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implants are rare [19–21]. Two prior studies with over 1313 shoulder arthroplasty cases have reported just two fractures around short humeral stem prosthesis, with a rate of <0.2% [20–21]. There have been no prior publications evaluating the impact of humeral stem length on the resulting periprosthetic humerus fracture patterns.

The purpose of this study was to evaluate periprosthetic humerus fracture patterns around short-stem versus standard-length stem shoulder arthroplasty implants. Our hypothesis was that fractures around a short stem are possible, and that there are differences in fracture patterns between short and standard stem implants.

Methods

This is a retrospective cohort study with a blinded dataset which evaluated humerus periprosthetic fracture patterns around short-stem and standard-stem shoulder arthroplasty humeral prostheses. The study received institutional review board approval prior to the initiation of data collection and review. There was no outside funding associated with this investigation.

Implants were classified as short-stem when the length of the prosthesis from head to stem tip was less than 100mm, and standard-length when the length of the prosthesis was greater than 100mm [22]. Patient inclusion criteria were age 40 or older sustaining a post-operative periprosthetic fracture of the humerus after having undergone hemiarthroplasty (HA), total shoulder arthroplasty, or reverse total shoulder arthroplasty. Exclusion criteria included periprosthetic fractures of the glenoid in isolation, proximal humerus fractures without the presence of a humeral prosthesis, humerus peri-implant fractures around plate-and-screw or intramedullary nail constructs, intra-operative humerus periprosthetic fractures, or unavailable injury radiographs depicting the humerus periprosthetic fracture.

Our institutional database (Banner Health, Phoenix, AZ) was queried using ICD-9 code 996.44 (periprosthetic fracture around prosthetic joint) in association with code 812 (fracture of humerus). We additionally searched for ICD-10 codes M97.3 (periprosthetic fracture around internal prosthetic shoulder joint), M97.31 (periprosthetic fracture around internal prosthetic shoulder joint, right), and M97.32 (periprosthetic fracture around internal prosthetic shoulder joint, left). Cases were collected from December 2011 (the initiation of using the current electronic medical imaging software at our institution) to January 2021. The collection of patient data was then reviewed and all available radiographs were screened for exclusion criteria. Charts and available imaging for the patients meeting inclusion criteria were then accessed and evaluated.

Patient characteristics and shoulder arthroplasty data were collected for each included patient. Radiographs were compiled and de-identified. Three fellowship-trained upper extremity surgeons evaluated all radiographs in a blinded manner. Each observer evaluated and commented on: 1) signs that the humeral stem may be loose prior to the fracture, as well as the stability of the humeral prosthesis after the fracture; 2) the Wright & Cofield [12] and the UCS [13] classification systems; and 3) the plan for optimal treatment based on the radiographs.

Signs that the prosthesis was loose prior to fracture included radiolucent lines or scalloping around the stem, as well as evidence of subsidence apparent by remodeling. Write & Cofield classification system was as follows: Type A) fracture is centered at tip of humeral stem, extending proximally >1/3 length of the stem; Type B) fracture centered at tip of humeral stem with minimal proximal extension, and Type C) fracture of humeral shaft distal to the tip of the prosthesis extending into the distal humeral metaphysis. Unified Classification System grading was: Type A) Fracture of bone apophysis; Type B1) Fracture around well-fixed humeral implant, good bone stock; Type B2) Fracture around loose humeral implant, good bone stock; Type B3) Fracture around loose humeral implant with poor remaining bone quality; Type C) Fracture in humerus distal to the implant. Type D) Inter-prosthetic fracture (between shoulder and elbow arthroplasties).

Observer data and classifications were pooled based on majority agreement, when there was no agreement a fourth investigator served as the tie-breaker.

A secondary analysis was performed using the same dataset, with the same methodology, to compare periprosthetic fracture patterns in cemented versus uncemented stems.

Statistical analysis was completed using Stata (StataCorp. 2017. Stata Statistical Software: Release 15. College Station, TX: StataCorp LLC). Continuous variables were compared using Student's t-test. Categorical variables were compared using Fisher's exact test. A p-value less than 0.05 was determined to be statistically significant.

Results

We identified 76 patients who sustained periprosthetic fractures around the humeral component of a shoulder arthroplasty prostheses. The mean age was 75 years, with 68 % (52/76) female. Patient characteristics are outlined in Table 1. The two groups were comparable in terms of gender, ethnicity, laterality of the fracture, rates of tobacco use and diabetes mellitus, type of shoulder prosthesis (HA, TSA, RSA), and type of humeral implant fixation (cemented versus uncemented). Patients had presented to the Emergency Department or clinic at our institution and may have had their initial arthroplasty procedure or subsequent treatment at an outside institution.

There was a total of 13 HA stems, 12 TSA and 52 RSA. The short stem group consisted of 18 patients, 10 of whom were female (56%) with a mean age of 72 years. The standard stem group consisted of 58 patients, 42 of whom were female (72%) with a mean age of 76 years. Fig. 1 displays a heat map of the fractures identified in patients with a short stem, while Fig. 2 similarly displays a heat map of fractures for patients with standard stem implants.

The results of radiographic evaluation of the included patients are presented in Table 2. Patients with a short stem were significantly more likely to be classified as having an unstable prosthesis after fracture (67% versus 33%, p=0.01). Significant differences were identified between the two groups upon evaluation of the UCS fracture patterns

Table 1
Patient demographic data.

Patient Characteristics	Short Stem (n=18) Mean ± std	Standard Stem (n=58)# Mean ± std	p-value
Age (years)	72±8	76±10	0.13
BMI (kg/m^2)	32±12	29±6	0.11
	n (%)	n (%)	
Gender			0.25
Male	8 (44%)	16 (28%)	
Female	10 (56%)	42 (72%)	
Ethnicity			0.29
White	17 (94%)	53 (91%)	
Hispanic	0 (0%)	4 (7%)	
Asian/Pacific Islander	0 (0%)	1 (2%)	
Other	1 (6%)	0 (0%)	
Laterality			0.58
Right	13 (72%)	36 (62%)	
Left	5 (28%)	22 (38%)	
Tobacco Use			0.39
No	15 (83%)	53 (91%)	
Yes	3 (17%)	5 (9%)	
Diabetes Mellitus			1.0
No	13 (72%)	41 (71%)	
Yes	5 (28%)	17 (29%)	
Shoulder Implant			0.33
Hemiarthroplasty	1 (6%)	11 (19%)	
Total Shoulder Arthroplasty	2 (11%)	10 (17%)	
Reverse Shoulder Arthroplasty	15 (83%)	37 (64%)	
Cemented			0.06
No	17 (94%)	41 (71%)	
Yes	1 (6%)	17 (29%)	

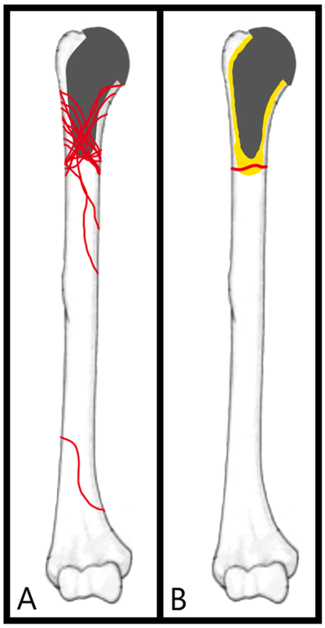

Fig. 1. Heat map illustrating the distribution of humerus periprosthetic fractures around A) uncemented and B) cemented short-stem prostheses.

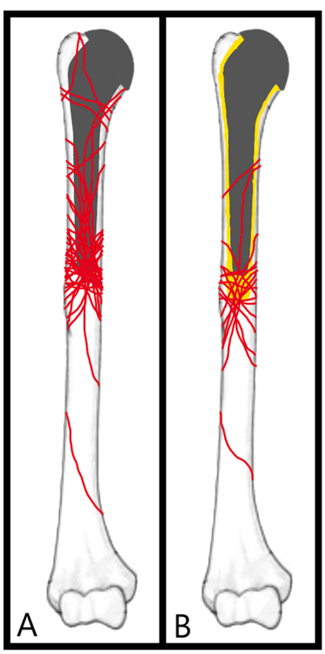

Fig. 2. Heat map illustrating the distribution of humerus periprosthetic fractures around A) uncemented and B) cemented standard-length stem prostheses.

(p=0.01) with more patients in the standard stem group having B1 fractures (fracture around the stem of a well-fixed implant, Fig. 3) (45% vs. 28%) and more patients in the short stem group having B2 fractures (fracture around the stem resulting in a loose implant, Fig. 4) (56% vs. 17%). In addition, the proposed plan for fracture treatment was different between the two groups (p=0.004): more patients in the standard stem group were recommended open reduction internal fixation (ORIF) (50% vs. 33%) or non-operative treatment (17% vs. 0%), and more patients in the short stem group were recommended revision arthroplasty (50% vs. 29%). The inter-rater reliability kappa statistic of the proposed plan for treatment was 0.41, which can be interpreted as moderate agreement.

Careful evaluation of the injury radiographs for signs of stem loosening pre-dating the periprosthetic fracture revealed no difference between the two groups. Two of 18 patients in the short-stem group had signs of pre-fracture loosening (11%), while 28% of patients with a standard stem had similar findings (p=0.21). Additionally, there was no significant difference in the distribution of the Wright & Cofield fracture classifications between the two groups, with a type B fracture seen in the majority of patients in both groups (p=0.44).

Table 2
Results of radiographic evaluation (Short vs. standard stems).

Stem characteristics	Short Stem (n=18) n (%)	Standard Stem (n=58) n (%)	p-value
Stem Status (After Fracture) *			**0.01**
Stable	6 (33%)	39 (67%)	
Loose	12 (67%)	19 (33%)	
Signs of Stem Loosening Prior to Fracture? *			0.21
No	16 (89%)	42 (72%)	
Yes	2 (11%)	16 (28%)	
Wright & Cofield Classification *			0.44
A	3 (17%)	14 (24%)	
B	11 (61%)	34 (59%)	
C	3 (17%)	10 (17%)	
Not Classifiable	1 (6%)	0 (0%)	
Unified Classification System *			**0.01**
A1	0 (0%)	1 (2%)	
A2	0 (0%)	0 (0%)	
B1	5 (28%)	26 (45%)	
B2	10 (56%)	10 (17%)	
B3	0 (0%)	11 (19%)	
C	3 (17%)	10 (17%)	
Not Classifiable	0 (0%)	0 (0%)	
Plan for Treatment *			**0.004**
Non-Operative	0 (0%)	10 (17%)	
Open Reduction Internal Fixation	6 (33%)	29 (50%)	
Revision to Standard Stem	3 (17%)	0 (0%)	
Revision to Long Stem	9 (50%)	17 (29%)	
Need Advanced Imaging	0 (0%)	2 (3%)	

* Values are reported as the average of the three observer classifications for each group.

The secondary analysis comparing periprosthetic fracture patterns in cemented versus uncemented stems is displayed in Table 3. Eighten patients had cemented stems: one patient with a short stem and 17 with standard stems. The remainder 58 patients had uncemented stems. There were no significant differences between the cemented and uncemented groups in terms of stem stability after the fracture, signs of stem loosening prior to the fracture, or the plan for treatment based upon radiographic analysis. There was a significant difference in the classification of these fractures using both systems, with cemented stems being more likely to have fractures completely distal to the prosthesis (type C fractures in both systems), compared to uncemented implants ($p < 0.001$).

Discussion

To our knowledge, this is the largest study of periprosthetic humeral shaft fractures associated with shoulder arthroplasty stems. This study is the first of its kind showing a difference in periprosthetic fracture patterns based on humeral stem length. Our results highlight several findings: 1) we found that periprosthetic humeral shaft fractures around short stems are possible, which was present in 24% of our 76 patients identified. 2) The majority (67%) of patients sustaining a periprosthetic fracture of the humerus around a short-stem implant had radiographic signs of component instability after the fracture. 3) Cemented implants were associated with more distal fractures, compared to uncemented implants which were associated with fractures close to the tip of the

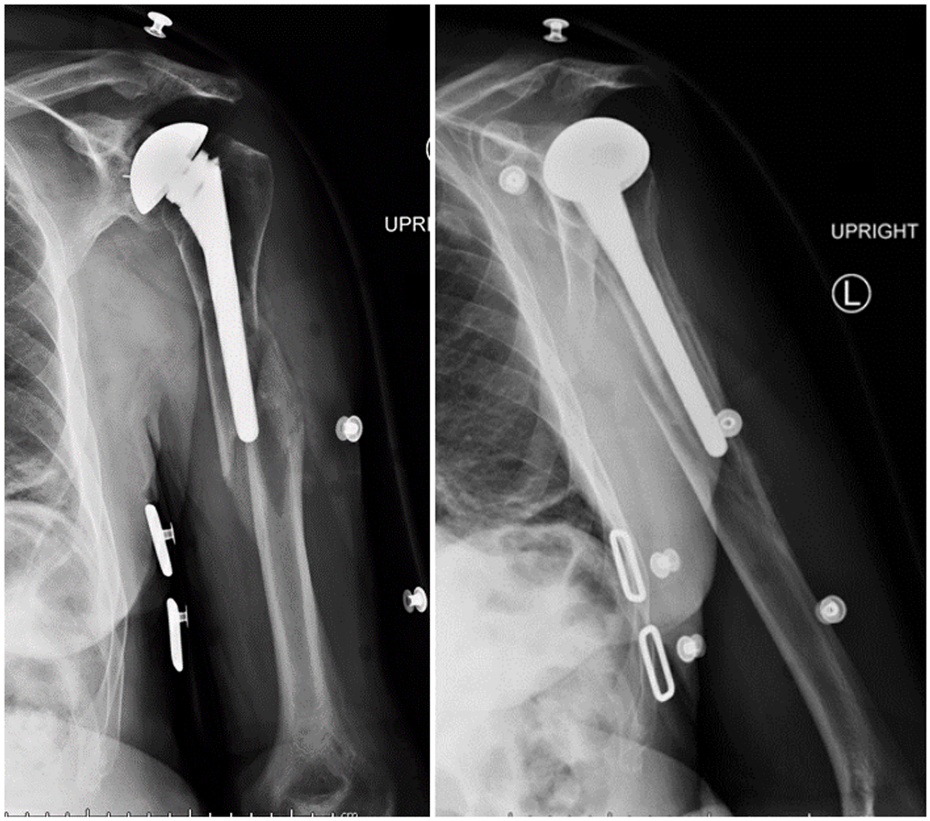

Fig. 3. Left shoulder anteroposterior and lateral radiographs of a 60-year-old male sustaining a proximal humerus periprosthetic fracture around a standard stem TSA implant. The humeral component radiographically appears stable.

Fig. 4. Left shoulder anteroposterior radiograph of a 72-year-old female sustaining a proximal humerus periprosthetic fracture around a short-stemmed RSA implant. The humeral component radiographically appears unstable.

implant.

Publications discussing peri-prosthetic fractures in short-stem implants are scarce. It has been suggested that short stem implants may be protective against periprosthetic fracturs [18]. Erickson et al. performed

Table 3
Results of radiographic evaluation (Cemented vs. uncemented stems).

Radiographic Evaluation	Cemented Stem (n=18) n (%)	Uncemented Stem (n=58)[#] n (%)	p-value
Stem Status (After Fracture) *			0.10
Stable	14 (77.8%)	31 (53.4%)	
Loose	4 (22.2%)	27 (46.6%)	
Signs of Stem Loosening Prior to Fracture? *			1.00
No	14 (77.8%)	44 (75.9%)	
Yes	4 (22.2%)	14 (24.1%)	
Wright & Cofield Classification*			**<0.001**
A	2 (11.1%)	15 (25.9%)	
B	7 (38.9%)	38 (65.5%)	
C	9 (50.0%)	4 (6.9%)	
Not Classifiable	0 (0.0%)	1 (1.7%)	
Unified Classification System*			**<0.001**
A1	0 (0.0%)	1 (1.7%)	
A2	0 (0.0%)	0 (0.0%)	
B1	6 (33.3%)	25 (43.1%)	
B2	0 (0.0%)	20 (34.5%)	
B3	4 (22.2%)	7 (12.1%)	
C	8 (44.4%)	5 (8.6%)	
Not Classifiable	0 (0.0%)	0 (0.0%)	
Plan for Treatment*			0.19
Non-Op Management	1 (5.6%)	9 (15.5%)	
ORIF	13 (72.2%)	22 (37.9%)	
Revision to Standard Stem	0 (0.0%)	3 (5.2%)	
Revision to Long Stem	4 (22.2%)	22 (37.9%)	
Need Advanced Imaging	0 (0.0%)	2 (3.4%)	

[*] Values are reported as the average of the three observer classifications for each group.

a systematic review of the literature, finding only 1 patient in 823 across 13 studies that was reported to be revised for a periprosthetic humerus fracture (0.1%) [19]. Tross et al. similarly found 1 reported case of post-operative humerus periprosthetic fracture in patients undergoing short-stem RSA out of 490 patients in 10 studies (0.2%) [20]. Our study reveals that 24% of fractures identified were around a short stem prosthesis. However, given the nature of our study we are unable to comment on the incidence of post-operative humerus periprosthetic fractures.

The two-dimensional heat maps we created highlight that the fractures around short stem implants are more commonly focused in proximal metaphyseal bone, without extending distally. However, the fractures around the standard stems are more distal, with more proximal bone stock present. Due to the proximal location of fractures in shorter stems, there may be inadequate quantity (as well as quality) of bone proximally, which can cause implant instability. Insufficient proximal bone and implant instability can make surgical fixation more difficult, and hence revision arthroplasty may be a more appropriate option. The higher rate of unstable stems in the short-stem group was reflected in the observers' classification of the fractures. The plan for treatment was also different given the increase stem instability, with 50% of short-stem patients being recommended for revision to a long-stem component compared to only 29% of the standard-length stem patients. Additionally, 50% of standard-stem patients were deemed amenable for ORIF on radiographic analysis as opposed to only 33% of the short-stem patients.

The result of our secondary analysis reveals that only 24% of patients received a cemented implant. This is likely due to the fact that routine cementing for humeral stems has fallen out of practice in the last decade, and patients undergoing humeral arthroplasty are more likely to have an uncemented implant. Cementing of short stems was rare (only one case), and 94% were uncemented, which was 23% higher than in the standard stem group—a difference nearing statistical significance ($p = 0.06$). We believe the reasoning for less cementing in the short stems is likely due to the fact that short stems are a newer design, and have only been popularized for the last 10 years, after routine cementing fell out of favor. There was no significant difference in the rates of standard-stem loosening after fracture between the cemented (22%) and uncemented (46%) humeral prostheses ($p=0.1$). While this did not meet statistical significance, it may be due to the small sample size, and more literature in this area is warranted. We did find that cemented stems were significantly more likely to have fractures distal to the prosthesis ($p<0.001$), however this finding did not lead to a statistically significant difference in the recommended treatment plan between the cemented and uncemented stem groups.

Although it was not the intention of this study, it also sheds light on the shortcomings of the Wright & Cofield classification system [12], which does not take into account stem stability or bone stock, and is limited in its ability to comment on fracture prognosis or direct treatment options. Poor interobserver reliability of this classification system has been reported in multiple studies [23,24]. The difference we found in humeral stem stability after fracture is reflected in the difference in the UCS classes [13] between the two groups. The UCS classification system takes stem stability into account, allowing this system to more effectively offer treatment recommendations. The majority of patients in the short stem group had type B2 fractures (loose implant, good bone stock; 56% of patients), while the most frequently occurring fracture type in the standard stem group was B1 (stable implant; 45% of patients). Because the Unified Classification System is more accurately able to guide treatment, it may be a more effective system to use when describing these injuries.

In addition to being the first study evaluating implant stem length and its impact on fracture patterns, to our knowledge this is the largest study evaluating periprosthetic fractures of the humerus following shoulder arthroplasty.

There are limitations to this study. One of the weaknesses which is inherent to any retrospective study is that we were limited to the data and imaging available in the medical record, which may have been inaccurate or incomplete. Although this is the largest case series to date, it may have limited statistical power due to the small sample size, especially when making group comparisons with varying sample sizes. Many patients received their index procedure and/or fracture management at outside institutions, and only the information regarding their periprosthetic fracture was available in our review. Treatment recommendations were also based upon radiographic evaluation only and not intra-operative findings, specifically with respect to stem loosening, which may under- or over-represent loosening. As such, the results of this study cannot be used to identify the clinical outcomes of these patients or directly dictate the ideal treatment methods in the periprosthetic fracture setting. Clinical follow-up data in this patient population would additionally be beneficial to evaluate outcomes of patients undergoing treatment for periprosthetic fractures of the humerus. Our study only evaluated the length of the humeral stem in relation to fracture patterns and did not take three-dimensional geometry of the stem into account. This may play a role in the clinically observed fracture patterns as well. Lastly, identification of periprosthetic fractures at our institution may be underrepresented as not all fractures may be coded properly and may be missed based on search criteria.

This study serves to identify a previously unrecognized periprosthetic fracture profile of short-stemmed shoulder arthroplasty procedures. While these results should by no means dissuade surgeons from using these implants, it is important to understand the fracture pattern and higher risk of stem instability in order to have an informed discussion with the patient preoperatively. Future research in this field could investigate the radiographic appearance of humerus periprosthetic fractures and their relation to intra-operative findings and actual treatment outcomes. Additional research could evaluate the clinical outcomes of periprosthetic fractures treated with surgical fixation vs. arthroplasty, as well as existing classification systems to determine which one is the most effective or propose a new, comprehensive system.

Conclusion

To our knowledge, this is the largest study of this type. The results suggest that patients sustaining a periprosthetic fracture around a short humeral stem are more likely to have an unstable prosthesis compared to a standard stem prosthesis. Moreover, cemented implants were more likely to sustain a fracture well distal to the stem, compared to uncemented implants that were more likely to sustain fractures near the tip of the implant. These differences in fracture patterns may affect the potential treatment options. Treating surgeons should be aware of these factors that increase the risk of humeral stem loosening when evaluating patients with periprosthetic humerus fractures and planning a treatment course.

Ethics statement

Authors certify that the manuscripts is their original work, and that the manuscript has not previously been published elsewhere.

CRediT authorship contribution statement

Niloofar Dehghan: Writing – review & editing, Supervision, Data curation. **Richard L. Auran:** Writing – review & editing, Methodology, Formal analysis, Data curation, Conceptualization. **Tram L. Tran:** Writing – review & editing, Formal analysis, Data curation. **Michael D. McKee:** Writing – review & editing, Supervision, Data curation, Conceptualization. **Evan S. Lederman:** Writing – review & editing, Data curation, Conceptualization.

Declaration of competing interest

None directly related to this manuscript.

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