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The Radiographic Union Score for Ulnar Fractures (RUSU) Predicts Ulnar Shaft Nonunion

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Conflicts of Interest:

None declared

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Abstract

Aims

To develop a reliable and effective radiological score to assess the healing of isolated ulnar shaft fractures (IUSF), the Radiographic Union Score for Ulna fractures (RUSU).

Methods

Initially, 20 patients with radiographs six weeks following a non-operatively managed ulnar shaft fracture were selected and scored by three blinded observers. After intraclass correlation (ICC) analysis, a second group of 54 patients with radiographs six weeks after injury (18 who developed a nonunion and 36 who united) were scored by the same observers.

Results

In the initial study, interobserver and intraobserver ICC were 0.89 and 0.93, respectively. In the validation study the interobserver ICC was 0.85. The median score for patients who united was significantly higher than those who developed a nonunion (11 vs 7, $p<0.001$). A ROC curve demonstrated that a RUSU ≤8 had a sensitivity of 88.9% and specificity of 86.1% in identifying patients at risk of nonunion. Patients with a RUSU ≤8 (n = 21) were more likely to develop a nonunion (n=16/21) than those with a RUSU ≥9 (n=2/33; OR 49.6, 95% CI 8.6-284.7). Based on a PPV of 76%, if all patients with a RUSU ≤8 underwent fixation at 6-weeks, the number of procedures needed to avoid one nonunion would be 1.3.

Conclusion

The RUSU shows good interobserver and intraobserver reliability and is effective in identifying patients at risk of nonunion six weeks after fracture. This tool requires external validation but may enhance the management of patients with isolated ulnar shaft fractures.

Word count: 246

Keywords:

Radiographic Union Score; Ulna; Fractures; Nonunion

Introduction

Isolated ulna shafts fractures are commonly caused by a direct blow to the raised forearm, known as a nightstick fracture[1]. Studies have shown that these injuries occur at a rate of 4 to 20 per 100,000 population per year[2,3]. One of the principal complications following an isolated ulna shaft fracture is nonunion, which results in pain and may require secondary fixation to stabilise the fracture to allow the bone to heal[6]. The rate of nonunion of non-operatively treated ulnar shaft fractures has been reported to range from 2-18%[1,4,5,24]. Nonunion of fractures are associated with considerable costs to the healthcare system and is shown in a nationwide epidemiological study to be more common in the upper limb, likely reflecting the higher incidence of upper limb fractures[23]. Early diagnosis of nonunion could help identify patients who may benefit from early operative intervention, therefore avoiding the morbidity that can result from an established ulnar shaft nonunion.

Recent radiological scoring systems have been proposed to help predict nonunion in fractures of the tibia[7,8], hip[9,10], humerus[11] and distal radius[12]. These systems assess the presence of callus to predict fracture union and have been shown to have good reliability. To the authors knowledge, no scoring system has yet been developed to assess fracture healing in ulna fractures or to predict nonunion in these injuries.

The primary aim of this study was to develop a reliable scoring system to assess the healing of ulnar shaft fractures – the Radiographic Union Scale for Ulna fractures (RUSU). The secondary aim was to investigate the utility of RUSU in predicting fracture nonunion at six weeks following injury.

Methods

Patients were retrospectively identified from a Picture Archiving and Communication System (PACS) database of forearm radiographs held at the study centre, which is a level 1 major trauma centre, over a period of 8 years from 2011 to 2018. Inclusion criteria were adult patients (aged ≥16 years at time of injury) with an isolated, closed fracture of the ulna diaphysis that were managed non-operatively, with no previous metalwork in place and an adequate set of anteroposterior (AP) and lateral radiographs taken at six weeks post injury. Exclusion criteria were patients who had surgical fixation of the fracture, patients with inadequate six-week radiographs and/or a pathological or periprosthetic fracture. There were 115 patients identified with radiographs suitable for RUSU scoring (Figure 1). The study received local audit committee approval and no external funding was received.

Management

All patients underwent routine non-operative management at the study centre, which consisted of application of an above-elbow backslab in the emergency department (ED), followed by fracture clinic follow up within two weeks of the injury for conversion into a lightweight cast/splint at the discretion of the treating orthopaedic trauma consultant. All patients were then brought back to clinic six weeks after injury for removal of cast, clinical examination and AP and lateral radiographs of the forearm.

Radiographic scoring

The RUSU scoring system was adapted from the Radiographic Union Score for HUmeral fractures (RUSHU)[11]. Each ulna cortex (volar, dorsal, ulnar, radial) was assigned a score between 1 and 3. A score of 1 corresponds to a cortex with absence of callus formation, 2 if nonbridging callus is present and 3 if fracture callus is bridging the fracture site. The scores of each cortex were combined to give a minimum score of 4 and a maximum score of 12.

Twenty radiographs were initially selected at random and rated by 3 independent observers (JML, WMO, KRB – all orthopaedic residents) to assess reliability and standardise scoring criteria. Following initial inter-observer reliability analysis, the 20 radiographs were re-scored 4 weeks later by the same observers to assess intra-observer reliability. Following refinement of the criteria, the 6-week radiographs of 18 patients who ultimately developed nonunion and 36 patients who united were randomly scored by the same three observers. Observers were provided with a single anonymised patient identifier and still images of the 6-week radiographs but were blinded to patient demographics and final images to reduce bias.

Statistical analysis

Statistical analysis was performed using SPSS version 27.0 (IBM Corp., Armonk, New York). Normality of continuous variables was assessed using the Shapiro–Wilk test; age at the time of injury was normally distributed. The relationship between categorical variables was assessed using a chi- squared test. The relationship between two groups of continuous parametric data was assessed using the independent-samples Student's t-test. Significance was set at $p < 0.05$; 95% confidence intervals (CIs) and two-tailed p-values were reported. The reliability of the RUSU was calculated using the intraclass correlation coefficient (ICC) and 95% CI. A two-way mixed model, with assessment of consistency between observers, was used to calculate a 'single measures' ICC. ICC is interpreted as follows: 0 to 0.2 indicates poor agreement; 0.21 to 0.4 indicates fair agreement; 0.41 to 0.6 indicates moderate agreement; 0.61 to 0.8 indicates substantial agreement; and more than 0.8 indicates almost perfect agreement[13]. A receiver operating characteristic (ROC) curve was used to determine the optimal RUSU cut-off score in predicting nonunion.

Results

RUSU development

In the pilot phase of 20 sets of radiographs, scored by three blinded observers, the mean RUSU was 9.2 (4 to 12, SD 2.3, 95% CI 8.2 to 10.2) and the median RUSU was 10 (IQR 7 to 11). The intraobserver ICC was 0.93 (95% CI 0.83 to 0.97) and the interobserver ICC was 0.89 (95% CI 0.74 to 0.96), both indicating near-perfect agreement.

The radiographs with the highest degree of disagreement were identified and a group discussion between the three observers was held to ensure uniform interpretation of the radiographs. A RUSU score of 2 for a cortex represents non-bridging callus (with a visible fracture line within it), irrespective of the amount of callus (Figure 2). A RUSU score of 1 for a cortex should be given when there is lack of callus even when there is a faint fracture line, despite a perceived progression to union based on the amount of callus in other cortices (Figure 3).

Validation and nonunion prediction

Following discussion and refinement of the scoring criteria, 54 sets of radiographs were selected, anonymised and randomised for the validation study. These included all the nonunions (n=18) presenting during the study period, and randomly-selected patients who achieved union (n=36). The patient demographics and characteristics are presented in Table 1. The nonunion group were more likely to have sustained a low-energy injury (p=0.02). There was no significant difference in other characteristics between the two groups. The mean RUSU was 9.2 (4 to 12, SD 2.4, 95% CI 0.65) and the median was 10 (IQR 7 to 11). The distribution of the RUSU scores is shown in Figure 4.

The interobserver ICC of the validation cohort at six weeks post injury remained excellent at 0.85 (95% CI 0.76 to 0.91). Subgroup analysis of reliability for specific cortices revealed that the ulna cortex on the AP radiograph showed the lowest reliability with an ICC of 0.62 (Table 2).

The median score for patients whose fractures subsequently united was significantly higher than those who developed nonunion (11 vs 7, p<0.001). A receiver operating curve demonstrated that a RUSU ≤8 had a sensitivity of 88.9% and specificity of 86.1% in identifying patients at risk of nonunion (Figure 5). The area under curve was 0.940 (95% CI 0.879 to 1; p<0.001). Patients with a RUSU ≤8 (n = 21) had 50 times greater odds of developing nonunion than those with a RUSU ≥9 (n = 33, odds ratio 49.6, 95% CI 8.6 to 284.7) (Table 3). Based on a PPV of 76%, if all patients with a RUSU ≤8 underwent fixation, the number of procedures needed to avoid one nonunion would be 1.3.

Discussion

This study has documented the development of a novel scoring system, the Radiographic Union Score for Ulnar fractures (RUSU), to assess the healing of isolated ulnar shaft fractures following non-operative management. The RUSU demonstrated excellent inter-observer and intra-observer reliability in assessing fracture healing at six weeks. It was also a strong predictor of nonunion at 6-weeks post injury, with a RUSU ≤8 associated with a significantly increased risk of nonunion. This system may be useful in targeting early (6-week) operative intervention to patients at increased risk of developing nonunion of an isolated ulnar shaft fracture.

Nonunion of the ulna is reported to complicate 2-10% of injuries and can result in pain, which may necessitate surgical fixation of the fracture to facilitate fracture healing[1,4,5,19]. Risk factors for nonunion of the ulna include fracture displacement, open fracture and fracture comminution, which are associated with higher energy injuries[4,20]. However, in our cohort low energy fractures were significantly more likely to develop fracture nonunion compared to high energy fractures. This may indicate that the use of baseline risk factors to predict nonunion may be inconsistent and highlights the need for a reliable radiographic tool.

The reliability of RUSU demonstrated in the current study would seem to be greater than that observed with other radiological scoring systems of fractures, such as the humerus with an ICC of 0.79 and the distal radius with an ICC of 0.62[11,12]. A potential explanation for this could be that majority of ulnar fractures in this cohort were of a simple fracture pattern. Long spiral fractures with larger amount of displacement may be more common in humeral shaft fractures resulting in more ambiguity in scoring[11]. This cohort only consists of patients who were treated non-operatively, whilst patients treated with surgery may be more challenging to score if the osteosynthesis plate obscures a particular cortex. Patients who are identified early to be at risk of nonunion can be managed with compression plating with bone graft, which have been shown to yield good results with high union rates[4,6,14,21].

Another advantage of the RUSU scoring system includes the use of plain radiographs that are readily available in most orthopaedic outpatient settings. This avoids the need for alternative imaging modalities such as CT and ultrasound scanning which are more costly, require training and/or are not readily available for point-of-care use in many centres[16]. A Cochrane systemic review has also highlighted the need of well-designed randomised trials to determine which method of treatment is the most appropriate for isolated fractures of the ulnar shaft in adults[2]. Whilst there is evidence to show that surgical fixation allows for early restoration of function and range of movement compared to conservative management[15,22], this may not translate to better functional outcome. However, these studies were limited by small sample sizes. The RUSU system would therefore provide a standardised, objective method of assessing bone healing in the research setting.

We acknowledge that there were five (24%) patients who had a RUSU score of ≤8 at six weeks who eventually went on to heal, and two (6%) with a RUSU of ≥9 who develop nonunion. However, this is relatively low compared to other studies that have documented attempts to predict nonunion. The two patients with nonunion and RUSU ≥9 had hypertrophic nonunion which resulted in a higher RUSU score. In both cases there was an initial progression of callus formation followed by cessation of callus formation after at least six months of follow up. Both cases underwent open reduction and internal fixation without bone grafting and went on to bone union. In our study, the area under the ROC curve is 0.94 compared with 0.84 for humeral fractures and 0.78 for distal radius fractures, demonstrating a generally excellent ability to discriminate between progression to healing versus nonunion[11,12]. Our data also suggests that if all isolated ulnar shaft fractures with a RUSU score of 8 or less at six weeks underwent open reduction internal fixation, the number needed to treat to prevent one nonunion is 1.3. Once externally validated, we would recommend the use of the RUSU system as an adjunct to clinical and radiological parameters such as pain, angulation and secondary displacement, the latter two of which have been shown to increase the rate of nonunion[15].

There are limitations of this study. Firstly, the intraclass correlation is useful in pointing out the precision of a scoring system but not the accuracy[17]. As there is no 'gold standard' modality to assess ulna fracture nonunion, this is an inherent flaw and future studies may consider validating against CT scans to assess fracture healing. Secondly, this system has not received external validation and whether these results can be replicated in other centres is needed. However, validation studies from other radiological scoring systems have demonstrated good reliability and repeatability[8,18].

In conclusion, the RUSU shows good inter-observer and intra-observer reliability and is effective in identifying patients at risk of nonunion six weeks after ulnar shaft fracture. This tool requires external validation but may enhance the management of patients with isolated ulnar shaft fractures.

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TABLES

Table 1. Patient demographics and injury characteristics by outcome for the validation study.

Factor	Union (n=36)	Nonunion (n=18)	p-value
Sex, female: male, n (%)	19:17 (53:47)	12:6 (67:33)	0.496*
Mean age, years (range, SD, 95% CI)	54 (17-97, 23, 47-61)	60 (18-91, 21, 50-70)	0.134+
Medical comorbidities, no: yes, n (%)	13:23 (36:64)	7:14 (38:62)	0.832*
Smoking			
Current smoker	7	6	0.538*
Ex-smoker	7	6	
Never-smoker	14	6	
SIMD			
1 (most deprived)	7	1	0.203*
2	8	6	
3	3	5	
4	6	2	
5 (least deprived)	12	4	
Mechanism			
Fall from standing	12	8	0.062*
Assault	5	2	
Fall from height	16	2	
Stress/fragility	2	4	
Unknown	1	2	
Injury Energy			
High	21	4	0.020*
Low	14	12	
Injury Side			
Right	15	6	0.767*
Left	21	12	
Fracture location			
Proximal	2	3	0.057*
Middle	12	10	
Distal	22	5	
AO classification			
A1	5	0	0.233*
A2	11	4	
A3	18	11	
B2	2	2	
C3	0	1	

*Chi-squared test

+Student's t-test

Table 2. The reliability of each cortex for the validation cohort.

Cortex	**Interobserver ICC (95% CI)**
Volar	0.79 (0.67 to 0.88)
Dorsal	0.71 (0.54 to 0.82)
Ulnar	0.62 (0.42 to 0.76)
Radial	0.68 (0.49 to 0.79)

Table 3: RUSU ≤8 as a predictor of nonunion – characteristics and clinical relevance.

	Union (n=36)	**Nonunion (n=18)**	
RUSU ≥9	31	2	NPV = 0.94
RUSU ≤8	5	16	PPV = 0.76
	Specificity = 0.86	Sensitivity = 0.89	p<0.001*

*Chi-squared test; statistically significant

NPV, negative predictive value; PPV, positive predictive value

FIGRES

Figure 1. Flow chart showing the inclusion and exclusion criteria used to identify patients.

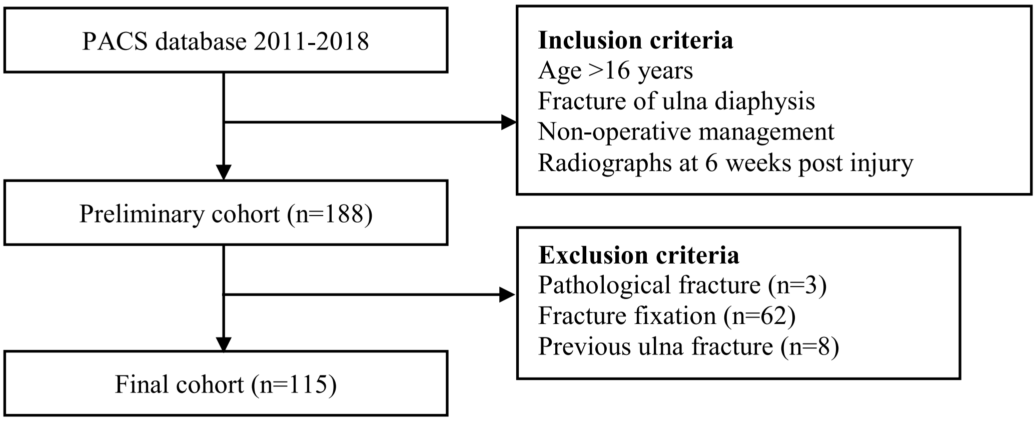

Figure 2. AP radiograph of the left ulna. Despite callus formation in the radial cortex of the fracture, the fracture line is still visible within the callus (highlighted red) and given a score of 2.

Figure 3. Lateral and AP radiographs of the left ulna. This radiograph shows an abundance of callus on the ulnar and volar cortex which indicates progression towards union however there is lack of callus on the radial cortex with a fracture line and therefore this should be given a score of 1.

Figure 4. Distribution of RUSU scores at six weeks for the validation cohort

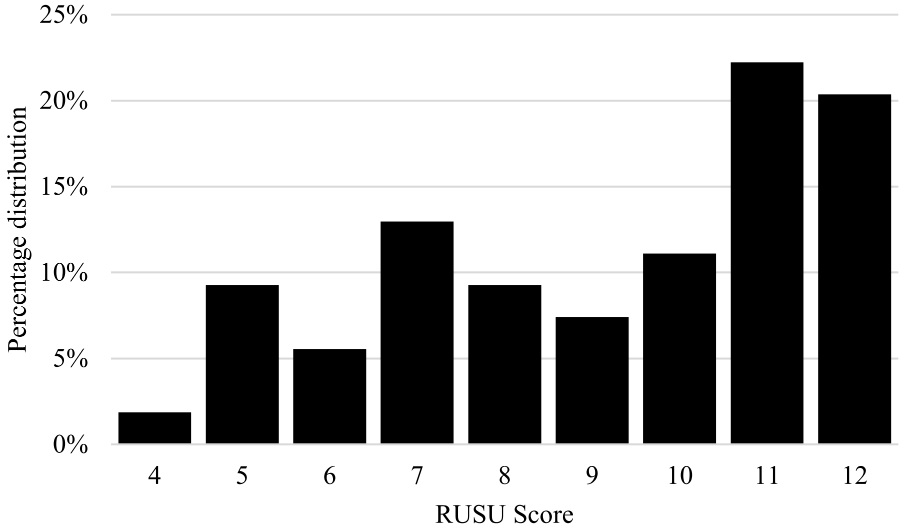

Figure 5. Receiver operating characteristic (ROC) curve for the RUSU (n=54). Area under curve = 0.940 (95% CI 0.879 to 1); p<0.001.