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ORIGINAL ARTICLE

Reliability of RUST and Modified RUST Scores for the Evaluation of Union in Humeral Shaft Fractures Treated with Different Techniques

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Abstract

Background The study aimed to evaluate the agreement between the radiographic union scale (RUST) and modified RUST (mRUST) in humeral shaft fractures treated with different techniques, and the effect of surgeons' experience and thresholds for determining bone union.

Materials and Methods A total of 20 orthopedic surgeons reviewed and scored radiographs of 30 patients with humeral shaft fractures treated by external fixation, intramedullary nailing, and plating using the RUST and mRUST on the 0 day, 6 weeks, 12 weeks and 24 weeks follow-up radiographs. Bone healing, interrater agreement between RUST and mRUST scores, and the threshold for radiographic union were evaluated.

Results The intraclass correlation coefficient (ICC) was slightly higher for the mRUST score than the RUST score (0.71 versus [vs.] 0.67). There was substantial agreement between the mRUST and RUST scores for external fixation (0.75 and 0.69, respectively) and intramedullary nailing (0.79 and 0.71); there was moderate agreement between them for plating (0.59 and 0.55). Surgeons with varying experience had a similar agreement for both scores and scores for each humeral cortex. The external fixation and intramedullary nailing group had higher RUST and mRUST scores than the plating group. The ICC for union was substantial (0.64; external fixation: 0.68, intramedullary nailing: 0.64, and plating: 0.61). More than 90% of the reviewers recorded scores of 10/12 for RUST and 13/16 for mRUST at the time of union.

Conclusions RUST and mRUST scores can be used reliably for the evaluation of bony union in humeral fractures treated with an external fixator and intramedullary nailing. In cases of humeral plating, a more sensitive tool for evaluation of fracture union is needed.

Keywords Humerus · Radiographic union · Humeral shaft fracture · External fixation · Intramedullary nailing · Plating · Surgeon experience · RUST score · Interrater agreement

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Introduction

Radiographic assessment of fracture union in combination with a physical examination is routinely used in the follow-up of patients treated for fractures [1]. The ability to describe the fracture healing and union have important roles in determining the success of the treatment and predicting patient outcome [2]. In the literature, there is not a uniform description of bone union [3, 4]. Previously, radiographic criteria for fracture healing included cortical continuity, fracture line visibility, the number of bridging cortices, and the surgeon's general impression [5]. Many methods have been developed to assess fracture healing and union [1, 3, 6, 7]. However, radiologic evaluation of bone union is still challenging because of the lack of consensus regarding which fracture healing assessment method most precisely represents bone union.

The radiographic union scale in tibial fractures (RUST) was recently developed to assess the healing of tibial shaft fractures after intramedullary nailing, and it uses a numerical value for each tibial cortex [8, 9]. It was based on bridging callus and fracture line visibility, which were found to be the most reliable signs of bone healing between observers [7]. The validity and reliability of the RUST score have been previously evaluated [9]. Yet, this radiographic scoring system does not propose an exact score to define bone union. A weakness of the RUST score is that the evaluation becomes dichotomous (i.e., the fracture line is visible or not) after bridging callus has occurred [2]. A fracture line that disappears with complete bone remodeling leads to a further subdivision in the cortical assessment with regard to the presence or absence of a cortical bridging callus [10]. To describe the radiographic healing progress more accurately, the modified RUST (mRUST) score was developed [2]. In addition to the standard RUST score, a fracture with callus formation was further subdivided as the callus being simply present or bridged [2].

In the literature, fracture healing has been assessed in different long bone fractures, different regions of bones, different age groups, different fixation methods, in-vivo models, and different fracture etiologies (i.e., primary, osteotomy, osteogenesis imperfecta, and fracture with segmental defects) using RUST and mRUST scores [2, 11–18]. To the best of our knowledge, evaluation of humeral shaft fracture healing using RUST and mRUST scores in different fixation techniques has not been performed yet. Therefore, this study aimed to evaluate the agreement between the RUST and mRUST scores in patients with humeral shaft fractures treated with external fixation, intramedullary nailing, or plating, as well as the effect of the surgeons' experience and thresholds for determining radiographic union.

Materials and Methods

After institutional review board approval, our clinical database for fractures was retrospectively evaluated. Patients with humeral shaft fractures who were treated operatively between 2013 and 2018 were identified. A total of 169 fractures were screened. Patients older than 18 years, having a closed humeral shaft fracture with complete bone union [19], and having undergone more than 1-year of follow-up were included. Exclusion criteria were as follows: (1) comminuted or segmental fractures, (2) fractures with delayed union or nonunion [20], (3) re-fractures, (4) the existence of a neurovascular injury, (5) pathological fracture, (6) a history of systemic infection, malignancy, chemotherapy or radiotherapy, (7) lack of or inadequate AP and lateral views obtained at the postoperative 0, 6, 12, and 24 weeks, (8) re-displacement or requirement of revision, and (9) fractures treated with cast and brace. After the exclusion criteria were applied, 63 fractures (10 external fixations, 19 nailings and 34 platings) were included in the study. A total of 10 radiographic sets from each treatment group (closed reduction–external fixation, closed reduction—intramedullary nailing, and open reduction—plating) were randomly selected for review. External fixation was performed in polytraumatized patients. A total of 20 orthopedic surgeons with varying levels of experience (Surgeons in the last year of their residency, surgeons with < 5 years of experience, 5–10 years of experience, and > 10 years of experience) who were blinded to the patient and radiographic data were invited to review 30 radiographic sets twice, with a 30-days interval between the first and second assessments of examiners. They were given descriptions of the RUST and mRUST scores based on the original papers by Whelan et al. [8] and Litrenta et al. [2], respectively. A total of 30 sets of images including AP and lateral radiographs obtained at the postoperative 0, 6, 12, and 24 weeks were included in a Microsoft PowerPoint file (Microsoft® Office 2011 for Mac; Microsoft, Redmond, WA). Radiographs were randomly arranged by a person blinded to the study; therefore, the fractures were not in chronological order. Further randomization was performed for the second evaluation. All standard AP and lateral projections were obtained using the same calibrated digital radiography system (DDR Inventor V (JSB Medics Co., Bucheon City, South Korea).

In the radiographic evaluation, each humeral cortex (anterior, posterior, medial, and lateral) was scored according to the RUST scale of 1–3 or mRUST scale of 1–4 (Table 1). Reviewers were asked to evaluate each humeral cortex and radiograph, and assign RUST and mRUST scores to each patient. In addition, they were asked to record whether the fracture was healed.

Table 1 RUST and modified RUST scoring systems

RUST score[8]			Modified RUST score[2]		
Score	Radiographic criteria		Score	Radiographic criteria	
	Fracture line	Callus		Fracture line	Callus
1	Visible	Absent	1	Visible	Absent
2	Visible	Present	2	Visible	Present
3	Invisible	Present	3	Visible	Bridging
			4	Invisible	Remodeled[a]

A score is assigned for each cortex and the total score is calculated by adding the scores assigned for each cortex. Minimum 4 points are assigned in RUST and modified RUST scores while maximum 12 points are assigned in Rust score and 16 points in modified RUST score

RUST radiographic union scale in Tibial fractures

[a]Remodeling was defined as the process of re-absorption and deposition of compact bone and re-shaping the bone toward its original shape [24]

Statistical Analysis

The mean, standard deviation, median, and minimum and maximum values were used in the descriptive statistics of the data. Intra- and inter-observer reliability was assessed using the intraclass correlation coefficient (ICC). The ICC with a 95% confidence interval was used to quantify the agreement between the RUST score and mRUST score by the treatment groups, surgeons' experience, cortices, and presence of bone union among the reviewers. On the basis of Landis and Koch's study [21], we defined 0–0.2 as slight agreement, 0.21–0.40 as fair agreement, 0.41–0.60 as moderate, 0.61–0.8 as substantial, and values > 0.81 as a perfect agreement in the ICC evaluations. SPSS version 22 (IBM, Corp., Armonk, NY) was used in the statistical analyses.

Results

A strong intra-observer agreement was observed regarding the individual RUST and mRUST scores (ICC: 0.88 and 0.91, respectively). The mRUST score had a higher ICC than the RUST score in humeral shaft fractures at various healing stages (0.71 versus [vs.] 0.67). Scores of the external fixation and intramedullary nailing groups had higher agreement than those of the plating group. There was substantial agreement between the mRUST and RUST scores for external fixation (0.75 and 0.69, respectively) and intramedullary nailing (0.79 and 0.71); there was moderate agreement between them for plating (0.59 and 0.55).

In the evaluation of agreement between RUST and mRUST scores for each of the four humeral cortices, we found that the lateral cortex of humeral fractures treated with plating had the lowest agreement (RUST 0.46 and mRUST 0.42). All ICC values for RUST and mRUST scores as well as for each humeral cortex are shown in Table 2.

Among surgeons with varying experience, total mRUST and RUST scores and scores for each humeral cortex at all time points showed similar agreement. Mean RUST and mRUST scores at the time of union in all patients and different treatment groups are shown in Table 3. The ICC for union was substantial (0.64; external fixation 0.68, intramedullary nailing 0.64, and plating 0.61). A score of 9/12 was considered by 79% of reviewers to indicate union when

Table 2 Intraclass Correlation Coefficient (ICC) values with 95% Confidence Interval (CI) for RUST and modified RUST scores of all patients, different treatment methods, and individual cortices

	RUST		Modified RUST	
	ICC	95% CI	ICC	95% CI
All patients				
Total	0.67	0.62–0.72	0.71	0.64–0.78
Medial	0.58	0.51–0.65	0.61	0.53–0.69
Lateral	0.51	0.46–0.56	0.59	0.50–0.68
Anterior	0.64	0.55–0.73	0.66	0.59–0.73
Posterior	0.51	0.43–0.59	0.60	0.53–0.67
External fixator				
Total	0.71	0.63–0.79	0.79	0.70–0.87
Medial	0.62	0.55–0.69	0.69	0.64–0.74
Lateral	0.56	0.49–0.63	0.60	0.52–0.68
Anterior	0.59	0.54–0.64	0.62	0.56–0.68
Posterior	0.66	0.60–0.72	0.72	0.65–0.79
Nail				
Total	0.69	0.61–0.77	0.75	0.69–0.81
Medial	0.60	0.57–0.63	0.67	0.62–0.72
Lateral	0.54	0.48–0.60	0.59	0.55–0.63
Anterior	0.65	0.60–0.70	0.73	0.67–0.79
Posterior	0.57	0.51–0.63	0.64	0.60–0.68
Plate				
Total	0.55	0.50–0.60	0.59	0.52–0.66
Medial	0.50	0.43–0.57	0.56	0.47–0.65
Lateral	0.46	0.39–0.53	0.42	0.33–0.51
Anterior	0.49	0.44–0.54	0.51	0.43–0.59
Posterior	0.52	0.46–0.58	0.54	0.45–0.63

Table 3 The mean RUST and modified RUST scores at the time of union decision

	RUST	Modified RUST
All patients	8.7 ± 2.3	11.5 ± 2.5
External fixator	9.2 ± 1.9	12.3 ± 2.4
Nail	9.0 ± 2.2	12.0 ± 2.9
Plate	7.9 ± 1.7	10.3 ± 2.3

using the RUST score. A score of 11/16 was considered by 73% of reviewers to indicate union when using the mRUST score (Table 4). More than 90% of the reviewers recorded scores of 10/12 for RUST and 13/16 for mRUST at the time of union. Figure 1 shows examples of humeral shaft fractures treated with external fixation, intramedullary nailing, and plating when > 90% of reviewers considered them united.

Discussion

The most important finding of this study is that it is the first to support the reliability of the two radiographic scoring systems, RUST, and mRUST, in the assessment of healing in humeral shaft fractures. The mRUST score had a higher ICC than the RUST score in various healing stages

Table 4 Percentage of reviewers who decided to union according to RUST and modified RUST score

Score	RUST			Modified RUST			
	8	9	10	9	11	12	13
Union %	46	79	92	24	73	85	95

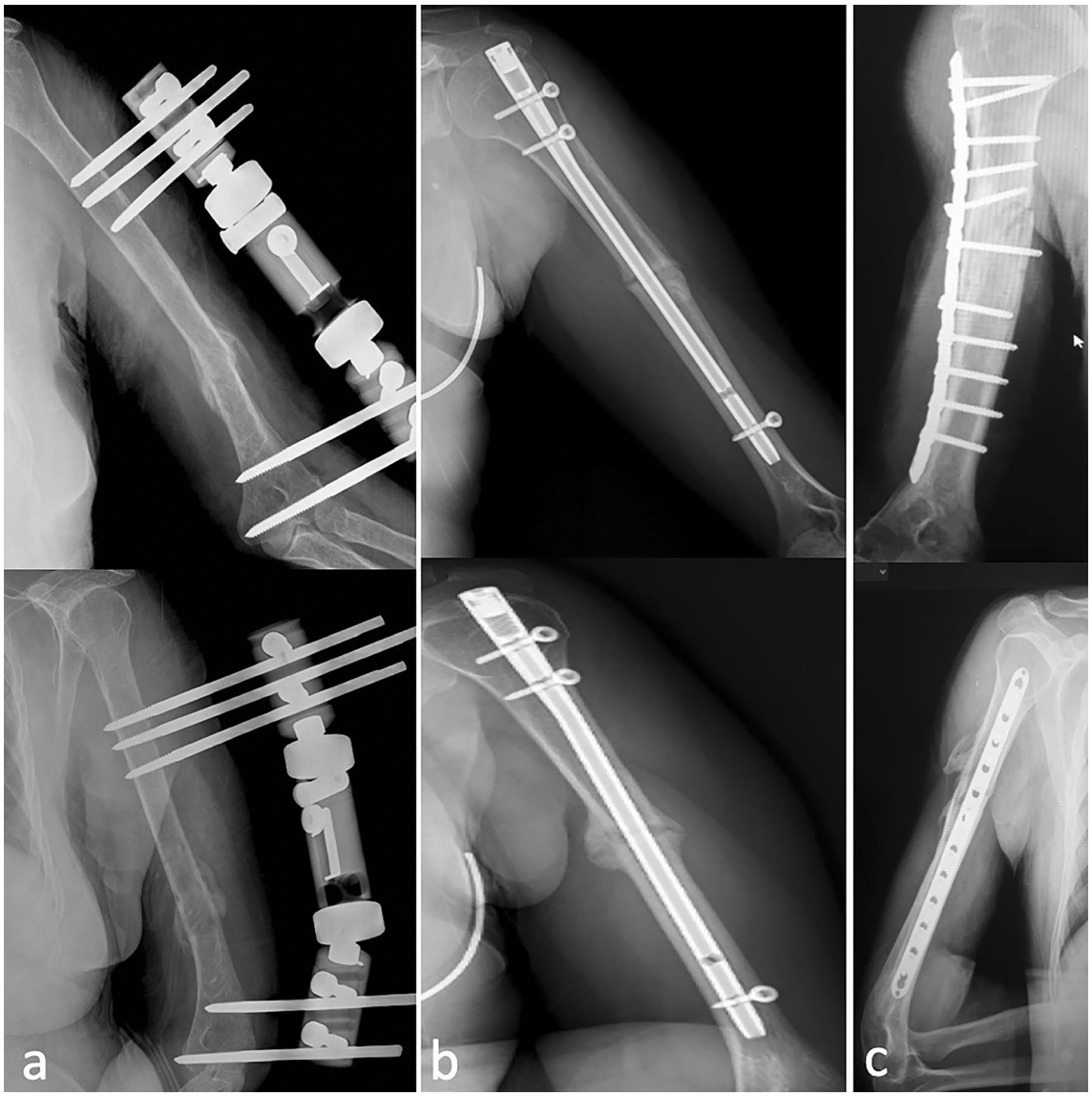

Fig. 1 AP and lateral view X-ray examples of humeral shaft fractures treated with external fixation (**a**), intramedullary nailing (**b**), and plating (**c**) when > 90% of reviewers considered union

of humeral shaft fractures. The scores of the external fixation and intramedullary nailing groups had higher agreement than those of the plating group. Additionally, there was substantial agreement between the mRUST and RUST scores for external fixation and intramedullary nailing, and there was moderate agreement between them for plating. Thus, the correlation between the union and the two scoring systems was shown. The lowest agreement between the scores was shown for the lateral cortex in humeral fractures treated with the plate. Minimum thresholds of 9/12 using RUST and 11/16 using mRUST may indicate a healed fracture, and scores of 10/12 and 13/16 would provide a confident assessment of union according to RUST and mRUST, respectively. Lastly, overall RUST and mRUST scores and scores for each humeral cortex showed similar agreement among surgeons with a different experience.

Substantial to excellent agreement with an ICC > 0.80 was previously shown for the RUST score in the radiographic assessment of tibial shaft fractures treated with intramedullary nailing [7, 22]. Although this scoring system is readily applicable to tibial shaft fractures treated with intramedullary nailing, open wedge high tibial osteotomy, metadiaphyseal fractures of the femur and tibia, callus formation and fracture line visibility differ based on the fracture location and fixation technique [2, 17]. In their study, Cristiano et al. evaluated the inter- and intra-observer reliability of the radiographic humerus union measurement (RHUM) scale in conservatively treated humeral shaft fractures [22]. They showed almost perfect intra- and inter-observer reliability of the RHUM. However, substantial agreement was observed when considering the fractures healed. They also reported that RHUM of 10 or higher as an excellent predictor of considering healed. In our study, we found substantial intra- and inter-observer reliability of mRUST and RUST scores for external fixation and intramedullary nailing, and moderate agreement for plating. More than 90% of the reviewers assigned the scores of 10 for RUST and 13 for mRUST at the time of union.

The fixation method affects the biomechanical environment of healing. Fractures that are treated with a brace and intramedullary nail are less rigid and form more callus than those treated with a plate [23]. When the union was evaluated, the overall RUST and mRUST scores were lower in the plating group than in the intramedullary nailing and external fixation groups. This difference between the scores for plating is due to the fact that this fixation method is more rigid than the others, and it results in less callus formation, making it difficult to evaluate the amount of callus formation that remains under the plate.

The presence of the plate may make evaluation and scoring of the lateral cortex more difficult [2, 17]. In our study, the lowest agreement between the scoring systems was found for the lateral humeral cortex during the 12-weeks radiographic evaluation.

The mRUST score, which is based on assigning a greater range of scores during the time of healing when the callus is bridged, was developed to achieve a more precise definition of the union. Because union occurs between the area of callus formation and remodeled cortices, the use of the mRUST score in the assessment of union provides a better indication of "healing" and "healed" [2, 5]. In our study, we found that according to the higher interobserver agreement, the mRUST score was slightly more reliable than the RUST score. However, both scores had a substantial agreement.

Litrenta et al. [2], the developers of mRUST, firstly considered the definition of union according to the ICC and the percentage of raters that assigned union. They reported that union is best defined by the percentage of reviewers assigning union with various scores despite the moderate absolute agreement between the reviewers. They also reported that minimum thresholds for the union of 9 for RUST and 11 for mRUST in metadiaphyseal fractures of the femur and tibia may be reasonable because of the majority of reviewers assigned union at those points. Further, they suggested that definite union would be scores of 10 and 13, respectively, with more than 90% of reviewers assigning union. In our study, we found that a score of nine was considered by 79% of reviewers to indicate union when using RUST, and a score of 11 was considered by 73% reviewers to indicate union when using mRUST. More than 90% of the reviewers recorded scores of 10 for RUST and 13 for mRUST at the time of union.

There are several strengths and limitations of this study that should be mentioned. This is the first study to evaluate the healing of humeral shaft fractures using the two radiographic scoring systems. We proposed score thresholds for the union by using the percentage of raters with various levels of experience. We also showed the lowest agreement between the scores according to time and the humeral cortex. Additionally, we compared three surgical treatment methods that cover most patients treated in clinical practice. Nevertheless, there were limited numbers of observers and cases in each treatment group. Further, evaluation by non-orthopedic observers was not performed, and this factor could have decreased the possibility of bias. However, observers were selected from a wide range of experienced surgeons. Evaluation of correlations with physical examination findings, pain scores, and functional outcome scores could enable surgeons to make more precise decisions about fracture healing and union. Closed reduction in the external fixator and nail groups and open reduction in the plate group might have been caused the total callus amount to differ and the scores to be affected. Scoring in fractures treated with a different type of plate might be different. Comparative

studies including various types of plates are needed to evaluate changes in RUST and modified RUST scores.

In conclusion, RUST and mRUST scores can be used reliably for the evaluation of bony union in humeral fractures treated with an external fixator and intramedullary nailing. In cases of humeral plating, a more sensitive tool for evaluation of fracture union is needed.

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Compliance with Ethical Standards

Conflict of Interest Abdulhamit Misir, Erdal Uzun, Turan Bilge Kizkapan, Kadir Ilker Yildiz, Murat Onder and Mustafa Ozcamdalli declare that they have no conflict of interest.

Ethical Approval This retrospective study involving human participants was in accordance with the ethical standards of the institutional and national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. The Clinical Investigations Research Ethics Committee (IRB) of Health Sciences University Metin Sabanci Baltalimani Bone and Joint Diseases Training and Research Hospital approved this study (Approval date and number 22.02.2018-24).

Informed Consent For this type of study informed consent is not required.

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