A radiographic and CT scoring system for quantification of the healing process in delayed-unions of long bone fractures: a feasibility study

Poster No.: C-1980
Congress: ECR 2013
Type: Scientific Exhibit
Authors: V. Perlepe, P. Omoumi, F. Lecouvet, B. Vande Berg; Brussels/BE
Keywords: Musculoskeletal bone, Trauma, CT, Conventional radiography, Comparative studies, Staging
DOI: 10.1594/ecr2013/C-1980

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Purpose

After fracture, bone has a tremendous potential for repair and regeneration to restore osseous continuity and function. Bone healing involves a complex integration of cells, growth factors and extracellular matrix. Unfortunately, delayed union occurs in about 10% of fractures and remains difficult to assess in clinical practice.

Limitations of radiographs in the assessment of fracture healing have consistently been demonstrated (1-4). There is little information on the potential role of computed tomography (CT) in the monitoring of fracture healing (5-7). New evidence demonstrates that CT has the potential to quantitatively assess bone defect healing in a pig model (6,7) as it enables to non-invasively probe the extracellular component of the healing process. Recent developments of CT acquisition and reconstruction protocols with reduced ionizing doses and increased multiplanar capabilities support the use of CT in clinical practice.

In this study, we proposed a Radiographic Union Score (RUS) derived from a published Radiographic Union Scale for Tibial fracture (RUST)(8). We also proposed a CT-based Tomographic Union Score (TUS). The aim of our retrospective study was to evaluate the feasibility of the RUS and TUS in a series of long bone non-unions stabilized either by intra-medullary nails or by plates. We also wanted to determine the intra-and inter-observer reproducibility when using RUS and TUS to score fractures.
Methods and Materials

Patients

A search in our picture archiving and communication systems (PACS)(Carestream Client version 11.3; Carestream Health, Rochester, NY, USA) was performed by one radiologist (BVB) to collect a series of long bone fractures in which radiographs and CT imaging studies had been performed within 4 weeks for the assessment of delayed unions over a period of 3 years (2009-2011). Exclusion criteria were (a) healed fractures, (b) metaphyseal or epiphyseal fractures, (c) open fractures, (d) fractures treated with allo- or auto grafts, (e) fractures with radiological or biological signs of infections.

The selected material included 23 cases of non-unions in 23 long bones (14 tibias, 4 femurs, 4 humerus, 1 radius) obtained in 22 patients including 13 male and 10 female patients (mean age : 41 yrs; min 19 years; max: 83 years; standard deviation: 16.9 years). The mean time delay between the fracture and the imaging studies was 28 months (min: 3 month; max: 180 months; standard deviation, 38.9 months). They were 2 cases of delayed- unions as defined by a time delay from fracture date less than 6 months and 21 cases on non-unions as defined by a time delay from fracture date more than 6 months.

Imaging protocols

All included patients had had radiographs and CT imaging within 30 days. The mean delay between radiographic and CT imaging studies was 7.3 days (min: 0 day; max: 28 days; standard deviation:9.4 days).

Radiographic studies included all antero-posterior and lateral radiographs of the involved body segment. All radiographs were performed on phosphor detector plates (Fuji Medical systems).

All unenhanced CT examinations were performed on a 40-detector row CT scanner (Somatom Definition AS; Siemens Healthcare, Forchheim, Germany). Patients were positioned supine, with the feet first for lower limb fractures and the head first for the upper limb fractures. Data acquisition was obtained over a mean length of 15 cm using the following tube parameters: tube voltage, 120 kVp; reference tube current-time product, 275 mAs. Effective current time-product , 178-305 mAs by applying Care Dose 4D (Siemens Healthcare); detector configuration, 40X0.6 mm; pitch, 0.8; gantry rotation time , 1 s. The CT raw data were reconstructed by using a conventional Feed-back projection algorithm. The following image reconstruction parameters were used: field-of-view, 12X12 cm to 20X20 cm; section/thickness increment, 0.75/.075 mm; soft tissue (B41s) and bone (B70h) convolution kernels.

Image analysis
One musculoskeletal radiologist with 21 years of experience and one 5th-year resident independently reviewed all CR examinations on a PACS workstation with adapted window width and level values. All cases were read in a random order without any clinical information. Both readers were blinded to CT studies.

Three months later, the same readers independently reviewed one mid-sagittal and one mid-coronal oblique multiplanar reconstructions that had been reconstructed by the MSK radiologist six months before according to the following parameters. All mid-sagittal and mid-coronal oblique CT reformats were obtained in a manner similar to that of the lateral and AP radiographs.

**Scoring systems**

A score was given to each cortical fracture segment on which the X-ray beam was tangent on the AP and lateral radiographs. On the AP radiographs and on the mid-coronal CT reformat of each case of delayed union, a score ranging from 1 to 4 was given to the medial and lateral aspects of the fracture. Similarly, a score ranging from 1 to 4 was given to the anterior and posterior aspects of each fracture. A total of 92 cortical bone areas were scored on the available radiographs and CT reformats. The RUS and TUS results of each delayed union corresponded to the sum of each of the 4 scores determined at the 4 cortical fracture sites. If 1 or 2 of the 4 data could not be scored (see below), the mean value of the three/two other scores was used as calculated data instead of scored data.

<table>
<thead>
<tr>
<th>RUS / TUS</th>
<th>Fracture line present</th>
<th>Fracture line absent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Callus absent</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Callus present</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>

The Radiological Union Score (RUS) and the Tomographic Union Score (TUS) systems were based on the presence or absence of a fracture line and of callus, on radiographs and on CT reformats respectively. The score were defined as follows:

Score 1 : Fracture line visible and no callus

Score 2 : Fracture line visible and interrupted callus

Score 3 : No fracture line and callus or fracture line visible and continuous callus

Score 4 : No fracture line, no callus

NA (Not Applicable) was used when the fracture site was not recognized due to superimposition of metal hardware from the considered or adjacent bone. It was also used when the cortical site of the considered bone was not clearly individualized due to superimposition with adjacent bone (leg and forearm).
Lesion definition

Fracture line

On radiographs and on CT reformats, a fracture line was defined as a cortical linear lucency with a length (longitudinal axis) of less than 10 mm related to the break and interruption of the cortical bone; The lucency reached the outer and inner cortical margins. Margins of adjacent bone edges were visible.

On radiographs, fracture line variants included (a) abrupt cortical deformity with sharp margins (angulation), (b) abrupt displacement of subperiosteal or endosteal cortical margins (translation/rotation) or (c) linear hyperdensity presumably related to superimposed bone fragments. Typically, this area of normal or increased bone density related to cortical bone superposition could be recognized only if either upper and/or lower cortical margins were delineated (visible cortical bone edges).

On radiographs, a fracture line should not be confused with a cortical defect which is defined as a cortical lucency of more than 10 mm long related either to formation and displacement of a bone fragment or to displacement of the cortical edges at the fracture site. The measurements must be performed along the longitudinal axis of bone. Fracture line should not be confused with vascular channels that have a round shape in transverse section and a smooth inner margin. On CT reformats, linear longitudinal lucencies that did not reach subperiosteal or endosteal bone were not taken into account.

Callus

On radiographs and on CT reformats, callus was defined by the presence of newly formed bone located either at the cortical edges or on the adjacent surface of the adjacent cortical bone. New bone formation corresponds to the presence of woven bone that lacks cortical and trabecular differentiation. New bone formation can not be differentiated from bone dust in the soft tissue near the fracture site. In case of doubt, the area of increased bone density in the soft tissue adjacent to the fracture line was considered to represent either bone dust or callus formation if the transverse axis of the area was longer or shorter than its longitudinal axis, respectively.

Statistical analysis

Complete feasibility, partial feasibility and non-feasibility of the RUS and TUS were defined as follows. Feasibility was complete when all cortical areas could be scored. Feasibility was partial when only one cortical area was rated NA. Non-feasibility was defined when 2 or more scored areas were rated NA.

To determine which features could interfere with scoring feasibility, we determined and compared the frequency of different parameters between the complete feasibility and the
non-complete feasibility (partial feasibility and non-feasibility). Frequency of the different parameters included age and sex, time delay from fracture (before or after mean delay), isolated (femur and humerus) or paired (leg and forearm) bones and plated versus nailed bones.

Intra- and interobserver variability was determined by using correlation coefficient for numerical variables and by using intra-class correlation coefficient for categorical data.
Results

A. Feasibility of RUS and TUS

RUS feasibility was complete in 15 (65%) cases for reader 1 and 12 (52%) cases for reader 2. RUS feasibility was partial in 7 cases for reader 1 and in 9 cases for reader 2. RUS was considered to be non-feasible in 1 case for reader 1 and in 2 cases for reader 2. Inter-observer reproducibility for the RUS feasibility was kappa=0.776.

TUS feasibility was complete in 23 (100%) cases for reader 1 and in 22 (96%) cases for reader 2. TUS feasibility was partial in 1 case for reader 2 (table). Inter-observer reproducibility for the TUS feasibility was kappa=0.844.

B. Comparison of complete feasibility frequency of RUS and TUS depending on clinical parameters

The frequency of complete feasibility of RUS and TUS for reader 1 and 2 is given in table 2. There was no difference in frequency of complete feasibility for RUS and TUS depending on sex, age and presence or absence of a paired bone. For both readers, the RUS, but not the TUS, was statistically significantly less frequently complete in case of a plated bone than in nailed bones. For reader 2, the RUS but not the TUS was statistically significantly less frequently complete in case of a non-union of less than 2 years than in non-unions of more than 2 years.

<table>
<thead>
<tr>
<th></th>
<th>RUS reader 1</th>
<th>RUS reader 2</th>
<th>TUS reader 1</th>
<th>TUS reader 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>F/M ratio</td>
<td>7 (70%)/8(62%)</td>
<td>4(40%)/8(62%)</td>
<td>9(90%)/13(100%)/0(100%)/13(100%)</td>
<td></td>
</tr>
<tr>
<td>Age (&lt;50/&gt;50)</td>
<td>6 (55%)/9(75%)</td>
<td>6(55%)/6(50%)</td>
<td>10(90%)/12(100%)/1(100%)/12(100%)</td>
<td></td>
</tr>
<tr>
<td>Isolated/paired bones</td>
<td>6 (66%)/9(64%)</td>
<td>4(55%)/8(57%)</td>
<td>9(100%)/13 (93%)/14 (100%)</td>
<td></td>
</tr>
<tr>
<td>Nail / plate</td>
<td>9 (82%)/1 (14%)</td>
<td>9 (82%)/1(14%)</td>
<td>10 (91%)/1 (100%)/7 (100%)</td>
<td></td>
</tr>
<tr>
<td>Delay from fracture</td>
<td>7(50%)/8(88%)</td>
<td>4 (28%)/8 (88%)</td>
<td>13 (93%)/9 (100%)/9(100%)</td>
<td></td>
</tr>
</tbody>
</table>

Table 2 Comparison of frequency of complete feasibility of RUS and TUS for reader 1 and 2 depending on age, sex, delay from fracture, body segment and orthopaedic hardware.
C. Inter- and intra-observer reproducibility of RUS and TUS

Inter-observer reproducibility of RUS was 0.89 at first reading and 0.73 at second reading. Intra-observer reproducibility of RUS was 0.86 for reader 1 and 0.92 for reader 2.

Inter-observer reproducibility of TUS was 0.85 at first reading and 0.89 at second reading. Intra-observer reproducibility of TUS was 0.97 for reader 1 and 0.83 for reader 2.
Fig. 1: Tibial non-union at a delay of 6 months after fracture in a 54-year-old woman. RUS was 5/6 (Reader 1/2).

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Fig. 2: Corresponding coronal and sagittal MDCT reformats (cf Fig 1). TUS was 4/5. Both techniques enabled visualisation of fracture line and callus.

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**Fig. 3:** Femoral non-union at a delay of 11 months after fracture in a 65-year-old woman. RUS was 9/9 (Reader 1/2).

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Fig. 4: Corresponding (cf. Fig 3) coronal and sagittal MDCT reformats. TUS was 7/8. Fracture line visibility was best appreciated on CT than on radiographs.

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Fig. 5: Tibial non-union at a delay of 12 months after fracture in a 48-year-old woman. RUS was 11/10 (Reader 1/2).

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**Fig. 6:** Corresponding (cf. Fig 5) coronal and sagittal MDCT reformats. TUS was 7/8. Fracture line was visible on CT but not on radiographs.

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Conclusion

In conclusion, this preliminary retrospective study demonstrated that a unique scoring system can be applied on either radiographs (RUS) or CT reformats (TUS) of long bone non-unions with a sufficient reproducibility to be tested in clinical practice. Results also suggested that the scoring system based on CT reformats (TUS) was more frequently successfully performed than that based on radiographs, partially because of underlying hardware in plated fractures. Further optimisation of radiations doses and prospective multicentre studies with readers of different qualifications are mandatory before to address the use of CT in evaluating fracture healing.
References


