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Can we assess healing of surgically treated long bone fractures on radiograph?

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KEYWORDS
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Abstract
Purpose: To determine the frequency and causes for limitations in the radiographic evaluation of surgically treated long bone fractures.
Materials and methods: Six readers separately scored 140 sets of antero-posterior (AP) and lateral radiographs of surgically treated long bone fractures, using a radiographic union score (RUS). We determined the rate of assessability of the fracture edges at each of the four cortical segments ($n = 560$) seen tangentially on the two radiographs and the causes for non-assessability. The rate of feasibility of the RUS (more than two fracture edges assessable per fracture) was determined and compared according to different parameters.
Results: Fracture edges were visible in 71% to 81% of the 560 cortical segments. Metal hardware superimposition was the most frequent cause for non-assessability (79—95%). RUS values could be calculated in 58% to 75% of fractures. Scoring was statistically significantly less frequently calculable in plated (31—56%) than in nailed fractures (90—97%), in distal (47—61%) than in proximal (78—89%) bones and in upper (27—49%) than in lower (76—91%) limb bones ($P \leq 0.01$).
Conclusions: The type of stabilization hardware is the main limiting factor in the radiographic assessment of surgically treated long bone fractures. Scoring was feasible in only 31% to 56% of plated fractures.

Abbreviation: RUS, Radiographic union score.

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Introduction

Musculoskeletal trauma represents an important global health burden with approximately six million fractures each year in the United States [1]. As many as 10% of these may be complicated by non-union with a subsequent increase in medical costs and productivity loss [2]. The evaluation of fracture healing is mainly based on clinical and radiographic findings, both presenting some limitations [3,4]. Clinical evaluation remains a subjective process [5—7] and limitations in the radiographic evaluation have also been demonstrated [5,6,8,9], while plain X-ray remains the examination of choice for bone fracture assessment [10]. Despite the added value of scoring systems for the overall evaluation of radiographs [11—17], radiologists and orthopaedic surgeons frequently hesitate when assessing fracture edges on radiographs [4,5]. Although there is general agreement on the fact that radiographs are limited by overlapping metal hardware [5,6,8], we are not aware of any study attempting to determine the parameters that limit the contribution of the radiographs and the consequences in feasibility of radiographic scoring systems [11—17]. The current study aimed at defining the frequency and causes for limitations in the quantitative radiographic evaluation of surgically treated long bone fractures.

Methods and materials

Study population

We selected a series of patients aged from 18 to 65 years with a surgically treated long bone fracture by searching in our picture archiving and communication systems (PACS) (Carestream Client version 11.3; Carestream Health, Rochester, NY, USA) using the keywords ''arm'', ''forearm'', ''thigh'' and ''leg'' among examination performed during a 2-year period. The search yielded a series of 613 sets of radiographs. A last-year radiology resident (VP) and a musculoskeletal radiologist with 20 years of experience (BVB) reviewed all radiographs to select patients with a surgically treated diaphyseal fracture and to exclude patients with one of the following exclusion criteria, including lack of surgically treated fracture, pathological fracture, preexisting metallic hardware or allograft in fractured bone segment, signs of infection or of delayed-union, or missing radiographs. The study population consisted of 118 patients including 76 men and 42 women (mean age: 41.3 $\pm$ 13.3 [SD] years; range: 18—65 years). There were 140 fractures (19 humeri, 19 radius, 17 ulnas, 26 femurs, 42 tibias and 17 fibulas). Thirteen patients had radial and ulnar fractures and 9 patients had tibial and fibular fractures. There were 63 nailed fractures (8 humeri, 1 ulna, 21 femurs, 31 tibias, 2 fibulas) and 77 plated fractures (11 humeri, 19 radius, 16 ulnas, 5 femurs, 11 tibias, 15 fibulas). For each of the 140 fractures, a data manager of our department selected one radiographic set among all available sets for each fracture to obtain an equivalent number of radiographic sets obtained at different time delays after the fractures for each type of bone. Time categories were defined as follows: between 0 and three weeks after fracture, between three weeks and three months after fracture, between three and six months after fracture and more than six months after fracture. The 140 sets of radiographs had been obtained at a mean delay of 114 days after fracture (standard deviation: 93 days; range 10—340 days).

Image analysis

Analysis of the radiographs was performed by six readers including three radiologists (a last-year resident [VP] and two musculoskeletal radiologists with three [AL] and 20 [BVB] years of experience) and three surgeons (a last-year resident [TS], and two orthopedists with five [DP] and 24 [JED] years of experience). All readers blinded to clinical findings separately analyzed each set of radiographs on a PACS workstation. Readers were asked to grade each of the four cortical edges of the fracture at which the X-ray beam was tangent as visible or not on the radiographs. When the fracture edges were visible, cortical scoring was

Table 1 Frequency of assessability and of non-assessability of the 560 fracture edges on the 140 radiographic sets for three radiologists (R1, R2, R3) and three orthopedic surgeons (O1, O2, O3). Frequency of causes for non-assessability of cortical fracture segments are given for each reader.

	Frequency of		Causes for non-assessability		
	Assessability	Non-assessability	Metal hardware superimposed	Cortical bone superimposed	Metal and bone superimposed
R1	407 (73%)	153 (27%)	120 (79%)	8 (5%)	25 (16%)
R2	409 (73%)	151 (27%)	143 (95%)	8 (5%)	0 (0%)
R3	426 (76%)	134 (24%)	110 (82%)	7 (5%)	17 (13%)
O1	420 (75%)	140 (25%)	112 (80%)	10 (7%)	18 (13%)
O2	398 (71%)	162 (29%)	141 (87%)	19 (12%)	2 (1%)
O3	452 (81%)	108 (19%)	94 (87%)	14 (13%)	0 (0%)

Results are raw data followed by percentages in parentheses. R1: last-year resident in radiology; R2: MSK radiologist with three years of experience; R3: MSK radiologist with 20 years of experience; O1: last-year resident in orthopedic surgery; O2 orthopedic surgeon with five years of experience; O3: orthopedic surgeon with 24 years of experience.

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