Computer-Reconstructed Radiographs Are as Good as Plain Radiographs for Assessment of Acetabular Fractures

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Abstract

Radiographic evaluation of acutely injured patients with a displaced acetabular fracture usually includes plain radiographs and computed tomography (CT) scans. Because of patient and technologist factors, plain radiographs can be compromised and therefore can be insufficient for assessment of the fractured acetabulum.

We conducted a study to determine whether computer-reconstructed radiographs (CRRs), plain radiograph–like images created from CT data, are equivalent to traditional radiographs for assessment of acetabular fractures. Five orthopedic surgeons with various trauma experience compared 77 radiographic images from 11 retrospectively identified patients with a displaced acetabular fracture.

CRRs were found to be equal to plain radiographs for fracture pattern recognition, image clarity, level of information provided, and overall reviewer satisfaction. Reviewers were confident in their ability to assess fractures using CRRs and found them more aesthetically pleasing than plain radiographs.

CRRs provide information equal to that of plain radiographs for assessment of displaced acetabular fractures and have the potential to overcome the problems associated with patient factors (discomfort, body habitus, fracture pattern, presence of overlying osseous structures, bowel gas and intestinal contrast materials) and technologist factors.

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Am J Orthop. 2008;37(9):455-460.

Standard radiographic assessment of displaced acetabular fractures includes an anteroposterior (AP) radiograph and oblique radiographs (Judet views) of the pelvis, plus a computed tomography (CT) scan.[1-7] Acquiring the oblique radiographs requires positioning the acutely injured patient with the fractured pelvis rolled 45° toward the x-ray beam and 45° away from the x-ray beam. This positioning is often a source of discomfort for the patient, and the standardized position is sometimes difficult to ensure. Because of patient factors (discomfort, body habitus, fracture pattern, presence of overlying osseous structures, bowel gas and intestinal contrast materials) and technologist factors, these radiographs often are of suboptimal quality.

CT scans often are used to overcome the shortcomings of traditional radiographs and have been shown to better identify certain fracture patterns, presence of intra-articular fragments, and degree of marginal impaction.[2,3,6,8] Typically, acetabular fracture classification and treatment decisions are based on plain radiographs and CT scans, making it necessary to obtain both for the assessment of patients with acetabular fractures. However, standard CT data can be used to create computer-reconstructed radiographs (CRRs), which mimic plain radiographs, and these images are not compromised by patient or technologist factors. Therefore, if CRRs are equivalent or superior to plain radiographs, they could eliminate the need for plain radiographs in the assessment of patients with acetabular fractures.

We conducted a study to compare the utility of CRRs with that of plain radiographs for the assessment of acetabular fractures. We also tried to determine whether the use of lateral images of the fractured hemipelvis acetabulum, after removal of the proximal femur (not possible with plain radiographs), offered any additional benefit of CRRs.

Materials and Methods

This study, approved by the Washington University School of Medicine Human Studies Committee Internal Review Board, was performed in the Department of Orthopaedic Surgery, Barnes-Jewish Hospital, Washington University School of Medicine, St. Louis, Missouri. Patient confidentiality was maintained in accordance with Health Insurance Portability and Accountability Act standards.

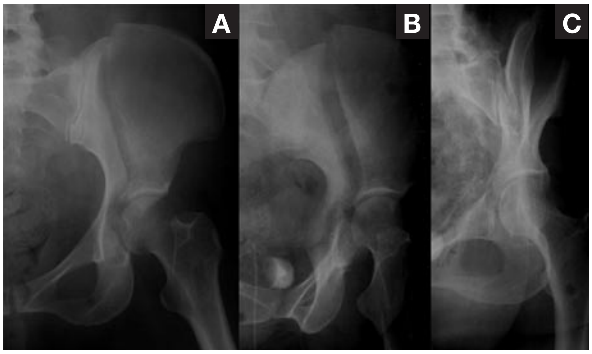

Figure 1. Anteroposterior (A), iliac oblique (B), and obturator oblique (C) plain radiographs of a displaced anterior column fracture (Orthopaedic Trauma Association 62-A). Such radiographs are obtained routinely in the emergency department.

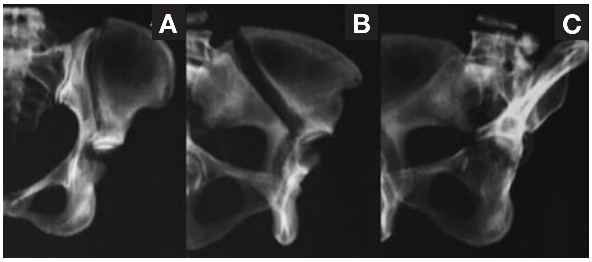

Figure 2. Anteroposterior (A), iliac oblique (B), and obturator oblique (C) computer-reconstructed radiographs of the anterior column fracture shown in Figures 1A–1C. Femoral head and proximal femur have been removed.

The operative log of the senior author (JB) was reviewed for adults surgically treated for a displaced acetabular fracture between January 2002 and August 2002. Twenty patients were identified, and their radiographs and CT scans were reviewed. Each eligible patient had a displaced acetabular fracture that required operative repair and a complete radiographic series, including plain radiographs (AP, iliac oblique view [IOV], obturator oblique view [OOV]) and an axial CT scan, performed at our institution. Eleven patients met these criteria, and their 77 images form the basis of this investigation.

Image Creation

Plain radiographs of the pelvis were obtained in the radiology suite or trauma bay of the emergency department. The images were obtained in a standard fashion for patient positioning and plate-to-beam distance, whereas exposure times varied according to patients' body habitus and technologists' experience and training. IOV and OOV were obtained using a 45° foam wedge to ensure consistent orientation of the pelvis, and all images were taken on standard-size cassettes (Figures 1A–1C).

CT scans were performed with a Somatom Plus 4 Power CT System (Siemens Medical Systems, Iselin, NJ). Data acquisition parameters varied in ranges of 120 to 140 KVp, 165 to 400 mA, slice thickness 2 to 3 mm, and table speeds 0.5 to 2.15 mm/s. For CRR creation, the data sets were transferred to a 3-dimensional (3-D) workstation (Silicon Graphics 02; Silicon Graphs, Inc., Sunnyvale, Calif) and modified with 3-D software (Vitrea 2.2; Vital Images, Minnetonka, Minn). This widely available commercial software has been determined to be accurate and reliable. Image postprocessing included segmentation techniques to remove the femoral head from the affected side to allow an even better view of the fractured acetabulum. Three images (AP, IOV, OOV) emulating the plain radiographs were printed on dry film (Blue-Base, Direct Vista 8×10 in) using a photographic printer (Codonics NP-1660; Codonics, Middleburg Heights, Ohio) (Figures 2A–2C). A true lateral image of the fractured hemipelvis, with the femoral head and proximal femur removed, was also included in the assessment (Figure 3).

Figure 3. Lateral computer-reconstructed radiograph with proximal femur removed allows full visualization of acetabulum and fracture.

Fracture Classification

The acetabular fracture pattern found at time of surgery by the senior author (JB) was used as the "true" fracture pattern for each patient. The intraoperative findings were used to classify the fractures according to Judet and Letournel.[1,9] There were 5 elementary and 6 associated types (11 total), including 4 transverse posterior wall, 3 posterior wall, 2 anterior column, 1 both column, and 1 posterior column plus posterior wall. According to the Orthopaedic Trauma Association classification of acetabular fractures, there were 6 partial articular, 1-column fractures, 4 partial articular transverse fractures, and 1 complete articular, both-column fractures.[10]

Image Evaluation

Images were reviewed by 5 orthopedic surgeons of varying experience (1 orthopedic traumatologist, 1 orthopedic oncologist, 1 hand surgeon, 2 orthopedic chief residents). During evaluation, process reviewers worked independently and without time constraint and were blinded to patients' identities, treatments, and outcomes. Image sets (3 plain radiographs, 3 CRRs) were randomized on a revolving light box such that the CRRs were presented before the plain radiographs for each patient. The images were labeled *AP, IOV,* or *OOV* to ensure correct comparison between corresponding CRRs and plain radiographs.

Table I. **Computer-Reconstructed Radiographs (N = 44): Mean Item Responses, From 8 (Most Useful) to 1 (Least Useful)**

	Computer-Reconstructed Radiograph						
	AP		IOV		OOV		
Variable	Mean	SD	Mean	SD	Mean	SD	*P**
Clarity of image	5.71	1.48	5.19	1.58	5.68	1.59	<.0001
Level of information	5.83	1.33	5.30	1.61	5.91	1.55	<.0001
Aesthetics	5.78	1.54	5.55	1.41	5.85	1.63	.004
Contrast	5.45	1.58	5.05	1.67	5.61	1.69	<.0001
Usefulness to classify fracture	5.75	1.54	5.22	1.76	5.84	1.63	<.0001
Usefulness beyond classification	3.91	1.58	3.78	1.70	4.24	1.76	<.0001
Confidence in classifying	5.71	1.59	5.24	1.73	5.74	1.66	<.0001
Overall satisfaction	5.75	1.67	5.15	1.79	5.73	1.68	<.0001

Abbreviations: AP, anteroposterior, IOV, iliac oblique view; OOV, obturator oblique view; SD, standard deviation.

Table II. **Plain Radiographs (N = 33) Versus CRRs (N = 44): Percentage Correct Responses and κ Statistics for Line Disruption and Fracture Pattern Classification**

	% Correct		κ Statistic		95% Confidence Interval		
Fracture	PR	CRR	PR	CRR	PR	CRR	Wilcoxon *P*
Iliopectineal line	85	88	0.71	0.76	0.53, 0.89	0.58, 0.93	.47
Ilioischial line	90	90	0.81	0.80	0.65, 0.97	0.64, 0.96	.61
Anterior wall	98	96	—	—	—	—	.54
Posterior wall	89	94	0.66	0.81	0.43, 0.9	0.6, 1.0	>.99
Associated vs elementary	89	91	0.78	0.82	0.61, 0.95	0.67, 0.97	.84

Abbreviations: PR, plain radiograph; CRR, computer-reconstructed radiograph.

A questionnaire, developed with Dr. Evanoff (an occupational environmental physician) specifically for this investigation, was completed by each reviewer for each of the 77 images. Responses were documented to a series of questions systematically assessing the quality and utility of each of these images. Grading was done on an 8-point visual analog scale. Subsequently, the questionnaires assessed the ability of the observer to identify the primary fracture lines and classify the fracture pattern according to Letournel. A simple line diagram of this classification system was included on all questionnaires for reference. Observers were then asked to view the plain radiographs and again identify the primary fracture lines and classify the fractures. Last, surgeons' preferences for CRRs versus plain radiographs were assessed with regard to the aesthetics and fracture pattern identification.

Statistical Analysis

Questionnaire responses were entered into a Microsoft Excel (Microsoft, Redmond, Wash) database, and data were analyzed with SAS (SAS Institute, Cary, NC). Kappa statistics were calculated to quantify observer agreement for categorical data. The guidelines of Landis and Koch were used to interpret the magnitude of agreement (0, poor; 0+, -0.2, slight; 0.21+, -0.40, fair; 0.41+, -0.60, moderate; 0.61+, -0.80, substantial; 0.81+, -1.0, almost perfect). Confidence intervals (CIs) were calculated for each κ. *P*s were based on the Kruskal-Wallis test for comparing numerical values, and Wilcoxon tests were used to compare responses for noncategorical data. Differences were considered significant when $P<.05$.

Results

Of the 11 patients, 7 were men, and 4 were women. Mean age was 37 years (range, 22-51 years), mean weight was 187 pounds (range, 135-379 pounds), and mean body mass index was 28.3 (range, 21-54).

Assessment of CRRs

AP, IOV, and OOV views were assessed for clarity, level of information provided in classifying the fractures, and reviewers' overall satisfaction with the images. In each assessment, a visual analog scale was used to rate responses from *most useful* (8) to *least useful* (1). For each category, there was no statistically significant difference among the 3 views (AP, IOV, OOV) ($P>.05$) (Table I). However, for all variables assessed, the lateral view was rated least useful ($P<.004$).

Agreement of CRRs With Surgical Findings

When *maybe* responses were disallowed, and the reviewers were forced to decide between presence or absence of a fracture, there was substantial agreement (κ, 0.82; 95% CI, 0.67, 0.97; 91% correct) between reviewers' assessment of CRRs and actual surgical findings. With regard to whether the iliopectineal line was disrupted, the reviewers responded conservatively, indicating the line was not disrupted in 6 images (12%), whereas it was in actuality. Conversely, the reviewers were more likely to indicate that there was either an anterior wall or posterior wall fracture in the absence of one only 5% of the time (Table II).

Agreement of Plain Radiographs With Surgical Findings

When *maybe* responses were disallowed, there was substantial agreement (κ, 0.78; 95% CI, 0.61, 0.95; 89% correct) between reviewers' assessment of plain radiographs and actual surgical findings. The reviewers exhibited the same trends with respect to incorrect answers with the plain radiographs as they did with the CRRs. Again, no disruption of the iliopectineal line was appreciated when one existed in 8 images (13%). The reviewers were more likely to indicate that there was an anterior or posterior wall fracture in the absence of one only 7.5% of the time (Table II).

In the analysis of the number of correct responses made with CRRs and plain radiographs, there was no statistically significant difference for any of the radiographic findings assessed ($P>.05$). Therefore, the accuracy of CRRs and plain radiographs in identifying fracture components was regarded as essentially the same.

Fracture Classification Using CRRs

With CRRs, substantial agreement was found between reviewers' classification of acetabular fractures and actual intraoperative findings (κ, 0.73; 95% CI, 0.59, 0.88; 80% correct). Reviewers were incorrect in classifying both-column acetabular fractures 75% of the time but perfect in classifying posterior wall acetabular fractures. When classifications were collapsed into only elementary and associated types, agreement was higher (κ, 0.82; 95% CI, 0.67, 0.97; 91% correct), with reviewers incorrectly classifying 4 fractures as elementary when in fact they were associated.

Fracture Classification Using Plain Radiographs

With plain radiographs, substantial agreement was found between reviewers' classifications and actual surgical findings (κ, 0.75; 95% CI, 0.61, 0.89; 82% correct). Consistent with assessment of CRRs, reviewers had the most difficulty evaluating both-column fractures (50%) and were most accurate classifying posterior wall fractures (100%). When potential choices for classification were collapsed into elementary and associated types, agreement was again higher (κ, 0.78; 95% CI, 0.61, 0.95; 89% correct), with reviewers incorrectly classifying 3 fractures in each group.

Direct Comparison of CRRs and Plain Radiographs

When the 3 CRRs were directly compared with the 3 plain radiographs, reviewers reported equal confidence in their ability to recognize the correct fracture pattern ($P = .15$) and thought there were no significant differences in image qualities ($P = .44$). Differences between CRRs and plain radiographs were found to be statistically significant for CRR-AP and -OOV and more aesthetically pleasing than their comparable plain radiograph views ($P<.05$), but there was no difference in assessment of the utility of the different images or in the aesthetics of the CRR-IOV ($P=.19$).

> "...because CRRs resemble plain radiographs, they can be used in the operating room for direct comparisons with intraoperative fluoroscopic images and after surgery for comparisons with immediate postoperative images."

Discussion

This investigation was undertaken to determine whether CRRs created from routinely collected CT scans are as good as plain radiographs for assessment of acetabular fractures. The premise was that, because CT scan quality is less compromised by patient and technologist factors and because CT scans can be used to create plain radiograph–like images, CRRs could be used instead of plain radiographs. In addition, because CT scans are routinely obtained during assessment of acetabular fractures, not only would the CRR technique not expose the patient to more radiation, but it would decrease the amount of radiation by eliminating the need for oblique views. Finally, because CRRs resemble plain radiographs, they can be used in the operating room for direct comparisons with intraoperative fluoroscopic images and after surgery for comparisons with immediate postoperative images.

In making their direct comparisons, each reviewer found CRRs comparable to plain radiographs for defining fracture lines and classifying fractures. CRRs were also found to be more aesthetically pleasing than plain radiographs, and the investigators thought that even lateral images with the femoral head removed (though found to be the least useful of the images) could potentially add to the assessment of acetabular fractures.

Other investigators have assessed the usefulness of axial CT scans alone and in conjunction with plain radiographs in the assessment of acetabular fractures.[2,5,6,8,11-15] While some have suggested that axial CT scans be used instead of plain radiographs, so far no one has presented convincing comparative data that would allow surgeons to be confident in replacing plain radiographs with CRRs. Three-dimensional CT scans have also been studied to determine their usefulness in assessment of acetabular fractures. Although certain advantages of these 3-D images over plain radiographs have been shown, their shortcomings, including cost and required technical expertise, have prevented them from becoming widely accepted and used in place of plain radiographs.[16] CRRs represent a blend of old and new technologies. Although these images take a mean of 10 minutes to create, they look like but do not have the same limitations as the familiar plain radiographs (Figures 2A–2C). Produced from CT data, they can be used in the operating room for comparisons with intraoperative fluoroscopic images and after surgery for comparisons with immediate postoperative images.

We note several study limitations. First, the number of patients whose radiographic images were used in this study is relatively small (11). However, each patient had 3 CRRs, 3 corresponding plain radiographs, and a lateral CRR evaluated (77 images total) by 5 orthopedic surgeons with an extensive questionnaire. Because statistical analysis of the results revealed high agreement and confidence intervals, a larger sample size would have yielded similar findings. Second, the retrospective nature of this study made it impossible to ensure standardization of the methods used to acquire plain radiographs. However, this is not so much a liability as an advantage. The radiographs we used had been made at an institution in which pelvic and acetabular fracture surgery has been performed routinely for at least the past 10 years. Thus, these everyday "radiographs" are of the same quality and have the same limitations as radiographs currently being used at other US institutions. CRRs were also made from CT scans obtained without a set protocol. Our study results have clearly shown that images made from routinely acquired CT scans are technically as good as plain radiographs for assessment of acetabular fractures. Despite no well-defined acquisition protocol, and despite reviewers' different levels of expertise, agreement among reviewers was high.

As CRRs were shown to be as good as plain radiographs for assessing displaced acetabular fractures, they should be considered replacements for plain radiographs. Development and use of a standardized protocol for CT data acquisition would further improve the quality of these images and would perhaps render unnecessary the need for plain radiographs in the assessment of displaced acetabular fractures.

> "In making their direct comparisons, each reviewer found CRRs comparable to plain radiographs for defining fracture lines and classifying fractures."

Authors' Disclosure Statement

Dr. McFarland wishes to note that she is a member of the Medical Advisory Board for Vital Images. The other authors report no actual or potential conflict of interest in relation to this article.

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Commentary

Digital radiography is widely used in orthopedics today, principally because of the advances in x-ray detectors, computers, networks, and displays that affect all aspects of medical imaging. Among the multitude of x-ray system designs that have been built and tested, one of the most common is the scout imaging for CT called computer-reconstructed radiography *(CRR) in this paper by Borrelli and colleagues. The origin of this technology and related terminology are worthy of mention.*

Pushbroom scanner systems build up an image using a linear detector array without the use of electromechanical components. In general, the detector array and object being scanned move in a rectilinear fashion relative to one another, and the detector output is recorded line by line on an image, much the same way a TV camera scans images. For example, the sensor onboard the NASA Landsat satellite that first flew in 1972 used this method to provide high-resolution images of the earth's surface.[1] The pushbroom scanner views objects through a slit that rejects scattered radiation, thereby improving image quality. Pushbroom x-ray scanners have been developed for chest radiography, mammography, and trauma imaging.

The pushbroom scanner concept was first used in computed tomography starting in the mid-1970s to provide scout images. The CT scanner's linear detector array rotation was disabled and it remained stationary below the moving table with the x-ray source at a fixed distance above. As the table was moved, this pushbroom x-ray scanner builds an image and paints it on a display. The method referred to as CRR in the paper by Borrelli and colleagues has been described many times in the medical physics and radiology literature under a variety of terms, including scanned projection radiography *(SPR),[2]* line scanned digital radiography,[3] *and, for radiation oncology virtual simulation treatment planning,* digitally reconstructed radiography *(DRR).[4]*

This contribution by Borrelli and colleagues measured the diagnostic value of CRR and conventional plain radiographs in adults with acetabular fractures. It is valuable to note that they found no significant diagnostic differences between the systems, but the scatter reduction and greater dynamic range of CRR resulted in better subjective image quality.

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