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Article

Quality of Mini C-Arm Imaging in Post-Reduction Evaluation of Distal Radius Fractures

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Abstract: Following closed reduction of distal radius fractures, formal radiographs are often obtained despite previous verification on fluoroscopy. A prospective collection of 60 consecutive distal radius fractures was obtained to compare the quality of the fluoroscopic images obtained from a mini C-arm versus formal radiographs. The images were reviewed by six orthopedic surgeons and one radiologist. The likelihood that further imaging was deemed necessary to guide treatment decisions was 1.9 times higher in the mini C-arm imaging cohort (95% CI: 1:34, 2.69). While mini C-arm remains a useful reduction aid, formal radiographs should still be obtained to document post-reduction alignment and to guide treatment decisions.

Keywords: distal radius fractures; closed reduction; fluoroscopic imaging

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1. Introduction

Utilization of mini C-arm fluoroscopic devices to evaluate hand, wrist, foot, or ankle pathology has increased in recent years presumably due to technical advances and improvements in the image quality of these devices. Advantages of the mini C-arm include ease of use, convenience, portability, and decreased radiation exposure to both operator and patient [1–4]. Since the physician operates the device, no additional technician is required, and the physician has complete control over positioning. Use of the "live" fluoroscopy feature allows passive and active motion to be assessed, and the area of interest can be "rolled" under the imaging beam, allowing multidimensional imaging. Use of the mini C-arm has the potential to improve the quality and ease of fracture reduction by enabling the provider to visualize alignment during or immediately following reduction maneuvers. This may decrease the need for repeated reduction attempts, decrease the length of sedation when required, improve emergency room flow, decrease radiation exposure to both patient and staff, decrease cost per diagnostic-related group, and improve the efficiency of care [5].

Although the mini C-arm is often used during distal radius fracture reduction and initial assessment, formal static radiographs are still considered the "gold standard" and used for the final confirmation and "documentation" even when mini C-arm images have been saved. Though mini C-arms have been shown to be adequate for evaluating post-reduction extra-articular distal radius and forearm fractures in the pediatric population [6,7], their adequacy in evaluating more complex wrist injury patterns has not been assessed. With improvements in image technology over the last decade, we hypothesize that mini C-arm imaging is adequate to evaluate intra- and extra-articular fracture alignment in all patient subgroups, obviating the need for formal post-reduction radiographs.

2. Materials and Methods

This study was initiated after approval by the Institutional Review Board (IRB). Statistical support was provided, in part, by the NIH National Center for Advancing Translational

Sciences through grant number UL1TR000058. A power analysis was performed to determine the appropriate sample size for this study.

Imaging was prospectively collected for 60 consecutive distal radius fractures initially evaluated in the emergency department (ED) of a Level I trauma center from October 2013 to January 2015. Except in situations of impending soft tissue compromise or a deformed, pulseless extremity, the patients being evaluated for suspected wrist fractures receive formal X-ray imaging, typically including the injured wrist, forearm, and elbow. These formal radiographs are used to assess the fracture pattern and determine the need for reduction and operative intervention. Fractures that did not require reduction, those that presented with open fracture or other devastating injury, and skeletally immature patients were excluded from the study.

In the operating room, fracture alignment was visualized intermittently and after final reduction with the aid of a mini C-arm (OrthoScan HD 1000, OrthoScan, Inc., Scottsdale, AZ, USA). Following reduction, a well-molded sugar tong splint with 10–12 layers of plaster is routinely applied. For this study, variability was allowed in splint thickness and technique, as commonly encountered in clinical practice. C-arm images to include anteroposterior (AP), oblique, and lateral wrist images following reduction and splinting were saved. Patients then underwent immediate formal post-reduction X-rays as per standard practice.

The obtained mini C-arm and X-ray images were then stripped of patient identifiers, randomized, and placed in an electronic survey format. Images for each imaging modality were then evaluated independently by three orthopedic trauma surgeons, three hand surgeons, and one radiologist not involved in the direct care of the patients included. These providers were asked to evaluate the images individually using two separate surveys (one mini C-arm and one X-ray). The viewers graded the quality and positioning of the images, estimated the articular congruence, distal radius tilt, and radial height, and determined if additional imaging was needed to guide further treatment. An example of the images utilized is seen in Figure 1, and an example of the survey is seen in Figure 2. After completing the first survey, the evaluators could not return to the survey and modify their responses.

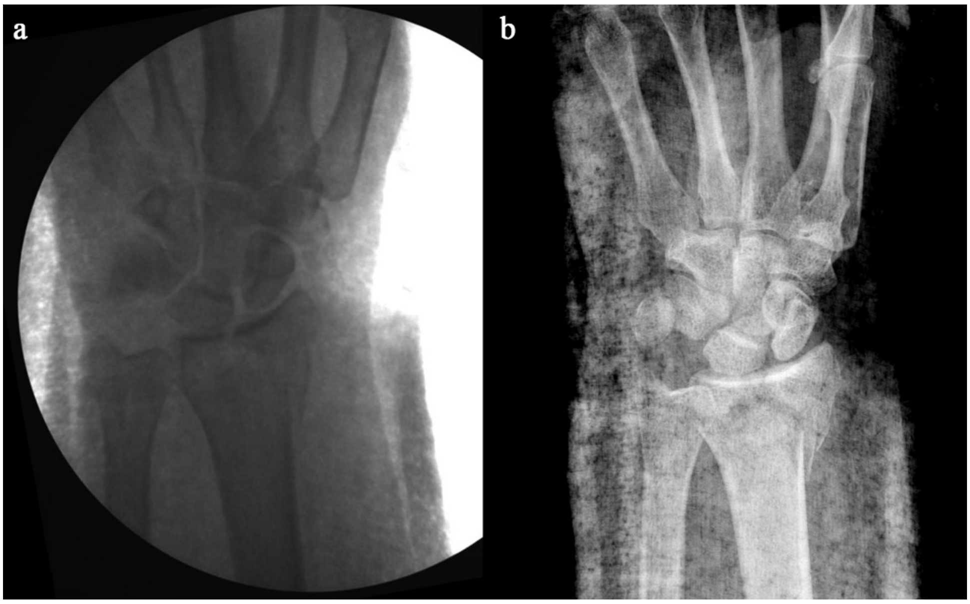

Figure 1. Example of mini C-arm and plain radiograph images. The mini C-arm image is marked by the letter (**a**) and the formal radiograph is marked by the letter (**b**).

1. Assess the positioning of the imaging. Is the AP a true AP?
(Perfect, adequate, or suboptimal)

2. Assess the positioning of the imaging. Is the lateral a true lateral?
(Perfect, adequate, or suboptimal)

3. How confident are you in your ability to determine the adequacy of the fracture reduction?
(Very confident, confident, neutral, or not at all confident)

4. Estimate the articular step-off of the radiocarpal joint.
(Anatomic (0mm), 1mm, 2mm, or >2mm)

5. Estimate the volar/dorsal tilt.
(>20° volar, 10° volar, neutral, 10° dorsal, or >20° dorsal)

6. Estimate the loss of radial height.
(None, <5mm, 5-10mm, or >10mm)

7. Do you feel that the quality of these images is adequate to guide treatment decisions?
(Yes - they are adequate or No- I need further imaging)

Figure 2. Example of survey questions addressed during the study.

Statistical Methods

Responses were then analyzed between the two imaging modalities on each patient as well as between specialties. The responses for the items assessing the adequacy of the positioning (AP and lateral), the ability to determine the fracture reduction, and the quality of the images to guide treatment decision were compared between the mini C-arm and X-ray images separately for each rater. Specifically, we reported the frequency and percentage of times each imaging technique was favored. For each item in the survey, a cumulative logistic regression model was used to determine if the responses regarding the two imaging modalities differed. Each of these models was adjusted for the rater completing the survey. Odds ratios (OR) and 95% confidence intervals (CI) were used to summarize all relationships.

3. Results

Over the time period from October 2013 to January 2015, 60 distal radius fractures requiring reduction were encountered in 57 patients (three patients presented with bilateral distal radius fractures). Of the study population, 19 patients (33%) were male, 38 (67%) were female, and the average age was 49.11 (±17.81) years old (range 19–92 years). In total, 21 (36.8%) of the mechanisms were considered high-energy (e.g., motor vehicle collision (MVC), motorcycle collision (MCC), fall from height), while 36 (63.2%) were considered low energy (e.g., ground level fall). Twenty-six of the fractures were intra-articular. Thirty-six patients required surgery. The surgical approach and implants were not recorded as part of this study. Four reductions were lost, three of which were treated operatively. Fifteen fractures were successfully treated non-operatively. Nine patients did not follow-up after the initial encounter.

The raw data demonstrating the frequency that mini C-arm was graded more favorably, equally, or less favorably than X-ray on the subjective questions (1, 2, 3, and 7) are shown in Table 1. A summary of the responses from our panel regarding the quality of positioning with the two imaging modalities is shown in Table 2. Mini C-arm AP and lateral positioning was graded to be sub-optimal in 17.14% and 30%, respectively; X-ray AP and lateral positioning was graded to be sub-optimal in 7.86% and 25.24%, respectively.

Table 1. Subjective results.

Rater	Mini C-Arm Better N (%)	Equal N (%)	X-Ray Better N (%)
Question 1: Assess the positioning of the imaging. Is the AP a true AP?			
Hand 1	3 (5%)	42 (70%)	15 (25%)
Hand 2	5 (8%)	25 (42%)	30 (50%)
Hand 3	8 (13%)	31 (52%)	21 (35%)
OrthoTrauma 1	5 (8%)	27 (45%)	28 (47%)
OrthoTrauma 2	18 (30%)	29 (48%)	13 (22%)
OrthoTrauma 3	16 (27%)	30 (50%)	14 (23%)
Radiologist	31 (52%)	24 (40%)	5 (8%)
Total	**20%**	**50%**	**30%**
Question 2: Assess the positioning of the imaging. Is the lateral a true lateral?			
Hand 1	9 (15%)	38 (63%)	13 (22%)
Hand 2	11 (18%)	15 (25%)	34 (57%)
Hand 3	15 (25%)	28 (47%)	17 (28%)
OrthoTrauma 1	14 (23%)	21 (35%)	25 (42%)
OrthoTrauma 2	20 (33%)	26 (44%)	14 (23%)
OrthoTrauma 3	20 (33%)	32 (54%)	8 (13%)
Radiologist	22 (37%)	31 (52%)	7 (12%)
Total	**26%**	**46%**	**28%**
Question 3: How confident are you in your ability to determine the adequacy of the fracture reduction?			
Hand 1	13 (22%)	24 (40%)	23 (38%)
Hand 2	16 (27%)	21 (35%)	23 (38%)
Hand 3	15 (25%)	37 (62%)	8 (13%)
OrthoTrauma 1	39 (65%)	16 (27%)	5 (8%)
OrthoTrauma 2	4 (7%)	27 (45%)	29 (48%)
OrthoTrauma 3	2 (3%)	12 (20%)	46 (77%)
Radiologist	26 (43%)	23 (39%)	11 (18%)
Total	**27%**	**38%**	**35%**
Question 7: Do you feel that the quality of these images is adequate to guide treatment decision?			
Hand 1	2 (3%)	49 (82%)	9 (15%)
Hand 2	16 (27%)	21 (35%)	23 (38%)
Hand 3	15 (25%)	37 (62%)	8 (13%)
OrthoTrauma 1	22 (37%)	34 (56%)	4 (7%)
OrthoTrauma 2	5 (8%)	16 (27%)	39 (65%)
OrthoTrauma 3	4 (7%)	31 (52%)	25 (42%)
Radiologist	n/a	n/a	n/a
Total	**17%**	**55%**	**28%**

Hand = hand surgeon; OrthoTrauma = orthopedic trauma trained surgeon.

Table 2. Summary of positioning quality.

	Mini C-Arm			**X-ray**		
	Perfect	**Adequate**	**Sub-Optimal**	**Perfect**	**Adequate**	**Sub-Optimal**
AP	17.86%	65%	17.14%	19.29%	72.86%	7.86%
Lateral	12.62%	57.38%	30.00%	12.86%	61.90%	25.24%

AP = anterior-to-posterior directed radiograph. Lateral = lateral or sagittally directed radiograph.

Results from the statistical analysis of the panel responses are summarized in Table 3. AP positioning of the X-ray group was favored over the mini C-arm group ($p < 0.05$). X-ray was also favored over the mini C-arm in the subjective assessment to determine fracture reduction and treatment decision making ($p < 0.05$). The odds of the mini C-arm AP imaging being judged as "Sub-optimal" compared to "Adequate" or "Perfect" was 2.42 times higher (95% CI: 1.55, 3.76) than for X-ray. Confidence in evaluation of fracture reduction with mini C-arm imaging had 1.97 times higher odds (95% CI: 1.19, 3.26) to be rated "Not confident" compared to all other options. The likelihood that further imaging was deemed necessary to guide treatment decisions imaging was 1.90 times higher for mini C-arm imaging (95% CI: 1.34, 2.69) than for X-ray.

Table 3. Results of statistical analysis.

Item	Comparison	OR (95% CI)	*p*
Positioning (AP)	Sub-optimal vs. (Adequate, Perfect)	2.42 (1.55, 3.76)	<0.05 *
	(Sub-optimal, Adequate) vs. Perfect	1.12 (0.78, 1.61)	0.54
Positioning (Lateral)	Sub-optimal vs. (Adequate, Perfect)	1.19 (0.87, 1.62)	0.27
	(Sub-optimal, Adequate) vs. Perfect	0.89 (0.59, 1.35)	0.60
Fracture Reduction	Not Confident vs. (Neutral, Confident, Very Confident)	1.97 (1.19, 3.26)	<0.05 *
	(Not Confident, Neutral) vs. (Confident, Very Confident)	1.65 (1.18, 2.30)	<0.05 *
	(Not Confident, Neutral Confident) vs. Very Confident	0.99 (0.69, 1.43)	0.97
Articular Step-off (Radiocarpal joint)	0 mm vs. (1 mm, 2 mm, >2 mm)	1.50 (1.13, 1.99)	<0.05 *
	(0 mm, 1 mm) vs. (2 mm, >2 mm)	1.12 (0.84, 1.51)	0.44
	(0 mm, 1 mm, 2 mm) vs. (>2 mm)	1.34 (0.93, 1.92)	0.11
Volar/Dorsal Tilt	>20 deg. volar vs. (10 deg. volar, Neutral, 10 deg. dorsal, >20 deg. dorsal)	0.88 (0.24, 3.17)	0.84
	(>20 deg. volar 10 deg. volar) vs. (Neutral, 10 deg. dorsal, >20 deg. dorsal)	1.08 (0.71, 1.64)	0.73
	(>20 deg. volar 10 deg. volar, Neutral) vs. (10 deg. dorsal, >20 deg. dorsal)	1.13 (0.82, 1.55)	0.47
	(>20 deg. volar vs. deg. volar, Neutral, 10 deg. dorsal) vs. >20 deg. dorsal	1.39 (0.77, 2.52)	0.27
Radial Height (Loss)	None vs. (<5 mm, 5–10 mm, >10 mm)	1.75 (1.20, 2.55)	<0.05 *
	(None, <5 mm) vs. (5–10 mm, >10 mm)	1.17 (0.88, 1.54)	0.28
	(None, <5 mm, 5–10 mm) vs. >10 mm	0.34 (0.89, 2.03)	0.17
Treatment Decision	Need further imaging vs. Adequate	1.90 (1.34, 2.69)	<0.05 *

Odds ratios (OR) larger than 1 are indicative of higher odds in the mini C-arm group compared to the X-ray group. * denotes statistical significance. AP = anterior-to-posterior directed radiograph.

There was a difference in grading of articular step-off and loss of radial height between imaging modalities ($p < 0.05$). Compared to X-ray, mini C-arm imaging had 1.50 times higher odds (95% CI: 1.13, 1.99) of assessing the articular step-off/alignment as anatomic compared to any other degree of malalignment. Mini C-arm also had 1.75 times higher odds (95% CI: 1.20, 2.55) of observing no radial height loss compared to any other option. There was no statistically significant difference between imaging modalities with respect to evaluation of dorsal/volar tilt.

4. Discussion

The mini C-arm has advantages of convenience, portability, ease of use, and safety with historically low risk of radiation [8–12]. With advances in portable mini C-arm image quality and theoretical advantages in surgeon-controlled positioning, formal post-reduction radiographs seem superfluous. We theorized that this practice potentially increased emergency room visit times, medical expense, and radiation exposure without clear clinical benefit. Our results demonstrate, however, that there is continued value in obtaining formal post-reduction radiographs.

The purpose of this study was not to demonstrate greater accuracy of one imaging modality over another, and indeed we did not attempt to correlate intra-operative findings with any of the radiographs or mini C-arm images. Our goal was to determine if post-reduction mini C-arm images provided adequate information to make medical decisions after the initial formal pre-reduction injury radiographs. Despite recent advances in mini C-arm image quality, we observed that radiographs provide superior detail. Our findings also suggested that dependence on mini C-arm imaging might underestimate key surgical determinants such as intra-articular step-off and radial height. This potentially concerning conclusion was further supported by a statistically significant lower confidence in medical decisions based on mini C-arm imaging alone as well as an increased perception that further imaging would be necessary.

Though surgeon-controlled positioning is one of the proposed advantages of mini C-arm usage, the hand surgeons and orthopedic trauma surgeons favored the formal X-ray positioning and images. As judged by formal X-ray, adequate fracture reductions were obtained with the use of mini C-arm, but in some cases appropriate mini C-arm images were simply not saved. The more standardized protocol practiced by the radiology technicians in this regard was clearly superior.

This study has strengths and weaknesses. The intra-operative and post-operative mini C-arm images were obtained by various surgeons of different backgrounds and skill levels. The experience level of the surgeons utilizing mini-arm and that of the technicians obtaining formal radiographs was not recorded. In many circumstances, the mini C-arm was operated by an orthopedic resident rather than a fellowship trained surgeon. While the residents were instructed on mini-c-arm use and appropriate imaging positioning, a more formal standard training protocol may have improved image quality. Mini C-arm advantages are clearly blunted when operated by less experienced or knowledgeable clinicians. The ability to "roll" the injured extremity under live fluoroscopy may provide additional benefits, which were not evaluated in this study. Only one mini C-arm was utilized; different devices may have resulted in different results. Certain raters may have inherently favored one imaging modality over another. The reviewers were not queried as to whether or not they preferred one imaging modality prior to being selected for the study. That said, this remains the largest prospective study to evaluate the quality and efficacy of mini C-arm images compared to X-ray images.

5. Conclusions

Both fluoroscopy utilizing a mini C-arm and formal radiographs have a role in patient care and fracture reduction. Despite the fact that mini C-arm images are controlled by the surgeon, our study demonstrated that these images do not provide the same quality that is obtained with formal radiographs. While the mini C-arm remains a useful reduction aid, formal radiographs should still be obtained to document post-reduction alignment and to guide treatment decisions.

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Institutional Review Board Statement: The study was conducted according to the guidelines of the Declaration of Helsinki and approved by the Institutional Review Board (or Ethics Committee) of Virginia Commonwealth University Health System.

Informed Consent Statement: The design of this study was reviewed by the Institutional Review Board, which determined that informed consent of the patients involved was not required.

Conflicts of Interest: The authors declare no conflict of interest.

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