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A Corresponding Point Measurement System Provides Reliable Measurement of Displacement for Medial Epicondyle Fractures

Ryan H. Guzek, MD, Kathleen Harwood, David Isaacs, Divya Talwar, PhD, Eric W. Edmonds, MD, Peter D. Fabricant, MD, MPH, V. Elaine Joughin, MD, FRCSC, Kevin H. Latz, MD, Stephanie W. Mayer, MD, Scott McKay, MD, Donna M. Pacicca, MD, Michael Saper, DO, and J. Todd R. Lawrence, MD, PhD

Investigation performed at The Children's Hospital of Philadelphia, Philadelphia, Pennsylvania

Background: Little consensus exists on the best method for evaluation and management of pediatric medial epicondyle fractures because of an inability to reliably evaluate fracture displacement with standard imaging techniques. This study aimed to determine the performance of various radiographic views in evaluating displaced medial epicondyle fractures when using a standardized measurement methodology.

Methods: Ten fellowship-trained pediatric orthopaedic surgeons assessed fracture displacement in 6 patients with displaced medial epicondyle fractures using radiographic views (anteroposterior, lateral, axial, internal oblique [IO], and external oblique [EO]) and computed tomographic (CT) views (axial, 3-dimensional [3D] horizontal, and 3D vertical). Raters used a corresponding point method for measuring displacement. For each image, raters measured the absolute displacement, categorized the percent of displacement relative to the size of the fragment and fracture bed, and indicated a treatment option. Interobserver reliability was calculated for each view. Bland-Altman plots were constructed to evaluate the bias between each radiograph and the mean of the CT methods.

Results: For absolute displacement, anteroposterior and EO views showed almost perfect interobserver reliability, with an interclass correlation coefficient (ICC) of 0.944 for the anteroposterior view and an ICC of 0.975 for the EO view. The axial view showed substantial reliability (ICC = 0.775). For the displacement category, almost perfect reliability was shown for the anteroposterior view (ICC = 0.821), the axial view (ICC = 0.911), the EO view (ICC = 0.869), and the IO view (ICC = 0.871). Displacement measurements from the anteroposterior, axial, and EO views corresponded to the measurements from the CT views with a mean bias of <1 mm for each view. However, the upper and lower limits of agreement were >5 mm for all views, indicating a substantial discrepancy between radiographic and CT assessments. Treatment recommendations based on CT changed relative to the recommendation made using the anteroposterior view 29% of the time, the EO view 41% of the time, and the axial view 47% of the time.

Conclusions: Using a corresponding point measurement system, surgeons can reliably measure and categorize fracture displacement using anteroposterior, EO, and axial radiographic views. CT-based measurements are also reliable. However, although the mean difference between the radiograph-based measurements and the CT-based measurements was only about 1 mm, the discrepancy between radiographic views and CT-based methods could be as large as 5 to 6 mm.

Level of Evidence: Diagnostic Level II. See Instructions for Authors for a complete description of levels of evidence.

Humeral medial epicondyle fractures account for 20% of elbow fractures in children[1]. Injury to this apophysis results from an avulsion by the ulnar collateral ligament in association with elbow dislocation or from the combined forces of the attached forearm flexor-pronator mass and the ulnar collateral ligament in the case of a throwing-related incident[1-6]. Irrespective of the mechanism, the fracture usually displaces distally and anteriorly along the pull of the flexor-pronator musculature[7].

Absolute indications for surgical intervention with open reduction and internal fixation include open fractures, incarceration of the fragment in the joint, ulnar nerve entrapment, and

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valgus instability[8-13]. Surgeons also use the magnitude of displacement as a relative operative indication; however, the displacement threshold to justify a surgical procedure remains controversial[14]. Arguments have been made for open reduction and internal fixation at perceived displacements ranging from 2 to 15 mm[10,12,15-18].

Although fracture displacement is often cited as an indication for surgical intervention, measuring fracture displacement on radiographs can be unreliable[19]. Additionally, although multiple medial epicondyle classification systems have been proposed[2,20-22], none is routinely used in practice.

As a result of the difficulties in reliably measuring displacement on radiographs, computed tomography (CT) with 3-dimensional (3D) reconstruction is often employed. Edmonds[7] compared the use of radiographs and 3D CT in the evaluation of nondisplaced fractures and found that both anteroposterior and lateral views can miss a substantial amount of anterior displacement in supposedly nondisplaced or minimally displaced fractures. More recently, an axial view was described by Souder et al.[23]. In a controlled laboratory study, they found the axial view to be reliable and to more accurately estimate the true displacement. Many clinicians now employ the axial radiograph in their clinical assessment. However, neither the reliability nor the performance of any of the radiographic measurements compared with CT have been assessed in real clinical cases.

The ability to reliably classify fractures and accurately measure displacement is key to comparing treatment outcomes between similar fractures. To do this, we first established a standardized methodology for measuring medial epicondyle fracture displacement. Using this methodology, this study aimed to determine the reliability of radiographic imaging studies, including the axial view, in the assessment of displaced medial epicondyle fractures and to determine the degree to which these radiographic measurements correlated with the displacement as assessed using CT methodology.

Materials and Methods

Imaging and Patient Selection

A power calculation indicated that 6 images measured by 10 raters would provide an adequate number of responses to assess measurement reliability. Six humeral medial epicondyle fracture cases that had all 5 radiographic views (anteroposterior, lateral, axial, internal oblique [IO], and external oblique [EO]) and 3 CT series (axial, 3D horizontal, and 3D vertical) (48 total images) were then randomly selected from a larger prospective cohort of patients presenting between 2014 and 2019 (Fig. 1). The axial view

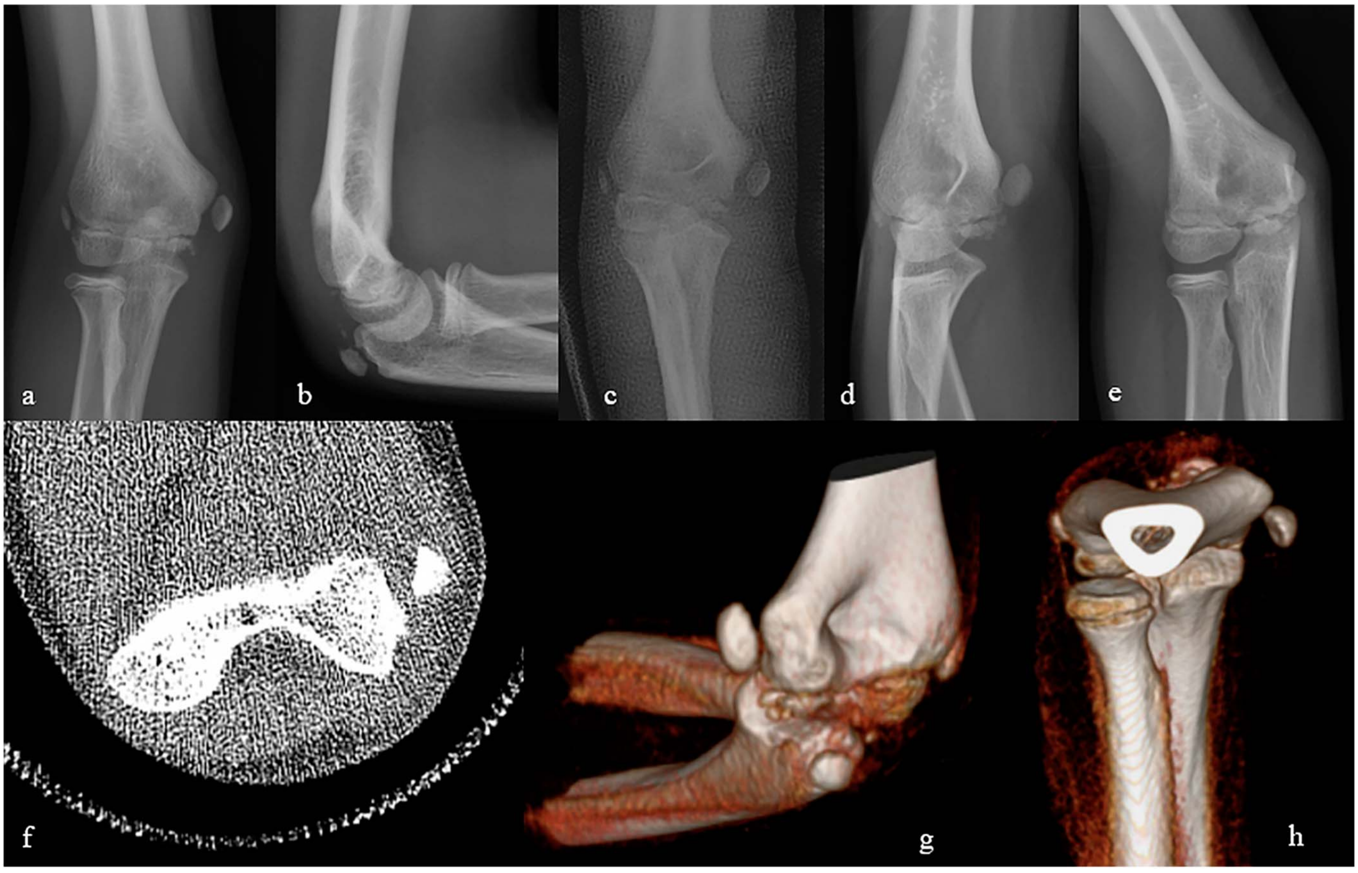

Fig. 1

Anteroposterior radiograph (**Fig. 1-A**), lateral radiograph (**Fig. 1-B**), axial radiograph (**Fig. 1-C**), IO radiograph (**Fig. 1-D**), and EO radiograph (**Fig. 1-E**) along with CT axial image (**Fig. 1-F**), CT horizontal image (**Fig. 1-G**), and CT vertical image (**Fig. 1-H**) for a 12-year-old boy who presented with a medial epicondyle fracture.

was obtained according to the positioning described by Souder et al.[23]. All images were acquired sequentially without orthopaedic manipulation performed between studies. Patients with additional fractures were excluded. Five patients were male, 1 patient was female, and patient ages ranged from 11 to 15 years. All injuries were sports-related, including 2 pitching injuries and 4 hyperextension injuries associated with a transient elbow dislocation. No case involved an incarcerated fragment. This study was approved by the host center's institutional review board.

Study Design

The 48 images were shuffled and were presented to 10 raters. Each rater was a fellowship-trained, attending pediatric orthopaedic surgeon experienced with the evaluation and management of medial epicondyle fractures. The images derived from a single case were not sequentially shown, and raters were unaware of which radiographs and CT series were associated. The radiographs and CT series were not presented in a staged fashion. As each image was presented in the picture archiving and communication software (IntelliSpace PACS; Philips), the rater was asked to measure the absolute displacement (in millimeters) of the fracture with the ruler tool using a corresponding point method (Fig. 2), categorize the percent of displacement relative to the size of the fragment and fracture bed (0% to 49%, 50% to 100%, >100%, incarcerated, or unable to determine), and select a treatment option (operative, nonoperative, or unable to determine) based on their individual operative criteria. There were no standard criteria for determining the need for a surgical procedure. All answers were recorded in REDCap[24]. Each rater was given written

Fig. 2

Corresponding point measurement method. Sample images displaying a simple displaced fracture (*top left*), double-density fracture (>1 fragment) (*top right*), and rotated fracture (*bottom left*), along with 3D CT reconstruction (*bottom right*). To perform the corresponding point measurement, points on the fracture bed and the fracture fragment that are thought to have corresponded to one another prior to the fracture are identified. The corresponding points with the longest distance from the fracture bed to the fracture fragment should be measured. For instance, for rotated fractures, measure from the proximal upper corner of the donor site to the presumed portion of the fragment that was originally attached there. If in doubt, measure on the proximal corner. Double-density contours are ones in which 2 edges (1 lighter and 1 darker) can be visualized at the fracture edge. In these scenarios, usually 1 light line appears to correspond with 1 darker line. If in doubt on these fractures, use the proximal corner of the darker line as the proximal corner. AP = anteroposterior.

instructions with examples of how to measure displacement using a corresponding point method before taking the survey. If a measurement could not be made using the provided image, the rater could indicate this on the survey.

Statistical Analysis

The results were collected and analyzed at 1 site. Intraclass correlation coefficient (ICC) estimates with 95% confidence intervals (CIs) were calculated for absolute displacement and displacement category using a 2-way random-effects model for absolute agreement[25]. The Fleiss kappa (κ) was used to calculate interobserver reliability for treatment decisions. ICC or kappa values were used to classify reliability as follows: <0.00 indicated no reliability, 0.00 to 0.20 indicated slight reliability, 0.21 to 0.40 indicated fair reliability, 0.41 to 0.60 indicated moderate reliability, 0.61 to 0.80 indicated substantial reliability, and >0.80 indicated almost perfect reliability[26].

We employed 3 statistical techniques to compare fracture evaluation between radiographic views and CT methods. First, we compared the absolute displacement between each radiographic view and a mean of all 3 CT methods using Bland-Altman plots, with the CT method assigned to the x axis[27-29]. The mean bias and associated 95% CI, upper and lower limits of agreement, and a trend line were applied to each plot. Second, the percentage of measurements made by each surgeon that differed by >2 mm between the radiographic measurement and each CT series measurement and between the radiographic measurement and the mean of all 3 CT series measurements was calculated. A difference of ± ≤2 mm was chosen as the predetermined acceptable limits of agreement, with a difference of >2 mm representing a clinically meaningful difference that may sway a surgeon's decision to operate[12,19,22]. Third, the disagreement rate between each radiographic view and individual CT methods was calculated for the percent displacement category (0% to 49%, 50% to 100%, >100%, incarcerated, or unable to determine) and for treatment choice. All reliability analyses and calculations of descriptive statistics were performed using SPSS version 27 (IBM), and all Bland-Altman statistics were calculated using the "blandr" package in R version 4.0.0 (The R Foundation for Statistical Computing).

Source of Funding

There was no source of outside funding for this study.

Results

Interobserver Reliability

The reproducibility of the corresponding point measurement system was assessed for each radiographic view and CT series by calculating the interobserver reliability (Table I). For absolute displacement (in millimeters), anteroposterior and EO radiographs demonstrated almost perfect interobserver reliability. The axial view showed substantial reliability. For the lateral and IO views, raters were not able to visualize the fracture displacement well enough to provide enough measurements to calculate an interobserver reliability. The CT axial and 3D horizontal views demonstrated almost perfect interobserver reliability. The 3D vertical view showed substantial reliability.

When asked to categorize the percent displacement as <50%, 50% to 100%, or >100% using radiographs, the anteroposterior, axial, EO, and IO views all demonstrated almost perfect interobserver reliability (Table I). The lateral view only showed slight reliability. Among the CT methods, the CT axial and 3D vertical views demonstrated almost perfect reliability. The 3D horizontal view showed substantial reliability.

Agreement Between Radiographs and CT

We next used Bland-Altman plots to assess the difference between the displacement measured with the anteroposterior, axial, or EO radiographic views and CT methods (Fig. 3). The mean bias in the absolute displacement (the difference relative to the mean of all CT methods) for the anteroposterior view

TABLE I Interobserver Reliability for Each Imaging View by Survey Question

	Absolute Displacement*	Percent Displacement*	Treatment
Radiographic view			
Anteroposterior	0.944 (0.829 to 0.993)	0.821 (0.525 to 0.970)	0.167
Axial	0.775 (0.173 to 0.994)	0.911 (0.754 to 0.985)	0.279
EO	0.975 (0.912 to 0.998)	0.869 (0.644 to 0.978)	0.267
IO	—†	0.871 (0.643 to 0.979)	0.062
Lateral	—†	0.123 (−0.291 to 0.753)	−0.016
CT view			
Axial	0.962 (0.869 to 0.997)	0.863 (0.630 to 0.977)	0.152
3D horizontal	0.844 (0.560 to 0.980)	0.773 (0.337 to 0.964)	0.169
3D vertical	0.761 (0.298 to 0.982)	0.934 (0.816 to 0.989)	0.134

*The values are given as the ICC (for displacements) or kappa value (for treatment), with the 95% CI in parentheses; values of >0.80 indicate almost perfect interobserver reliability, values of 0.61 to 0.80 indicate substantial interobserver reliability, and values of <0.41 indicate no or fair interobserver reliability. †A reliability calculation could not be performed because an insufficient number of raters could measure displacement.

was −0.4 mm (95% CI, −1.2 to 0.4 mm); however, the limits of agreement were −6.5 mm (95% CI, −7.9 to −5.1 mm) and 5.8 mm (95% CI, 4.35 to 7.12 mm). The mean bias for the axial view was 0.6 mm (95% CI, −0.3 to 1.5 mm). This view also had wide limits of agreement at −5.8 mm (95% CI, −7.4 to −4.3 mm) and 7.0 mm (95% CI, 5.4 to 8.6 mm). Although the mean bias for the EO view was −0.8 mm (95% CI, −1.7 to 0.0 mm), the limits of agreement were also widely distributed from −6.9 mm (95% CI, −8.4 to −5.5 mm) to 5.3 mm (95% CI, 3.8 to 6.7 mm).

All 3 radiographic views overestimated the CT measurements at lower magnitudes of absolute displacement and underestimated at higher magnitudes, as shown by the trend line displayed on each plot in Figure 3. Bland-Altman plots comparing each of the 5 radiographic views with each of the 3 individual CT methods are not shown, but the trends were similar.

We also assessed the percentage of radiographic measurements that differed from the CT measurement by at least 2 mm (Table II). When compared with the mean of the same observer's CT measurements, measurements differed by >2 mm on anteroposterior views on 44% of occasions, axial views on 46% of occasions, and EO views on 51% of occasions.

The degree to which the displacement classification using the radiographs differed from the classification noted using CT was also assessed (Table III). Categorization based on the CT scan changed relative to the anteroposterior view at a mean rate of 56%, to the axial view at a mean rate of 63%, and to the EO view at a mean rate of 57%.

The degree to which any radiograph influenced a rater to recommend a surgical procedure was also compared with the treatment decision based on the ability to fully evaluate the

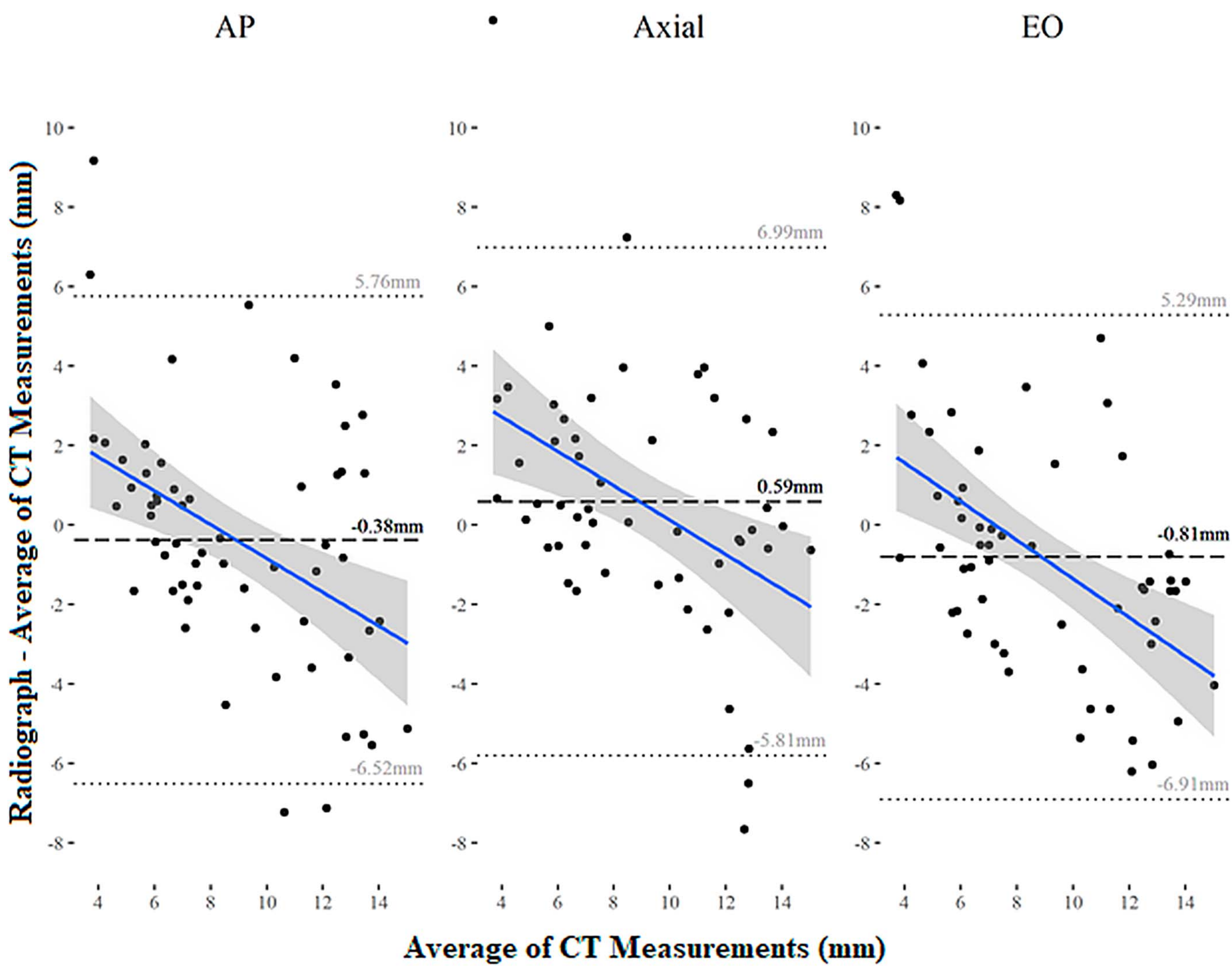

Fig. 3

Bland-Altman plots for analysis of the agreement between a mean of the CT measurements and anteroposterior (AP) radiographs (n = 59), axial radiographs (n = 52), and EO radiographs (n = 55). The mean bias (dashed line), limits of agreement (dotted lines), and simple linear regression fit have been applied to each plot.

TABLE II Percentage of Disagreement on Absolute Displacement Between Radiographic and CT Methods*

Radiographic View	Axial CT	3D Horizontal CT	3D Vertical CT	Mean CT†
Anteroposterior	52% (n = 56)	60% (n = 57)	49% (n = 57)	44% (n = 59)
Axial	52% (n = 51)	37% (n = 51)	36% (n = 50)	46% (n = 52)
EO	40% (n = 52)	54% (n = 54)	66% (n = 53)	51% (n = 55)
IO	67% (n = 33)	61% (n = 33)	53% (n = 34)	56% (n = 34)
Lateral	67% (n = 21)	55% (n = 20)	57% (n = 21)	52% (n = 21)

*Percentages were calculated as the number of comparisons with a >2-mm difference between the measurements divided by the total number of comparisons made. If either a radiograph or a CT measurement was unable to be made by the rater, both the radiograph and CT values were excluded from analysis. †The mean CT value was calculated as the mean absolute displacement across all available CT measurements (axial, 3D vertical, 3D horizontal) for each fracture according to each rater.

fracture with a CT scan (Table IV). Management changed the least for the anteroposterior view, with the treatment recommendation using CT only differing 29% of the time. When a decision that was made using the anteroposterior view differed from the decision that was made using the CT scan, 77% of the time that change was from nonoperative treatment based on the anteroposterior view to operative treatment based on the CT scan. In over half of these cases, the displacement was measured to be ≤10 mm on the anteroposterior radiograph but >10 mm on the CT scan. Treatment recommendations based on the axial and EO views differed more frequently than those based on the anteroposterior view, with 47% of the former and 41% of the latter differing from the treatment decision made on the basis of the CT scan.

Discussion

A major challenge in clinical decision-making for humeral medial epicondyle fractures is uncertainty whether published comparative studies have truly assessed patients with similar injuries. This controversy largely exists because it is unclear if the injury severity and degree of fracture displacement are fully represented on standard elbow radiographs. CT scans may provide a better representation of the injury pattern but involve a greater radiation exposure. An isolated arm CT has been shown to deliver a mean effective dose of 0.14 mSv, which is equivalent to about 1.75 chest radiographs[30]. Conversely, the exposure from an extremity radiograph is <0.001 mSv, over a hundred-fold less than a CT scan. Given that lifetime cancer risk is associated with radiation exposure, minimizing exposure without compromising our ability to make clinical decisions is a priority.

TABLE III Disagreement on Percent Displacement Category Between Radiographic and CT Methods*

Radiographic View	Axial CT	3D Horizontal CT	3D Vertical CT	Mean
Anteroposterior	52%	60%	55%	56%
Axial	70%	58%	60%	63%
EO	52%	58%	60%	57%
IO	70%	70%	67%	69%
Lateral	78%	82%	80%	80%

*Disagreement is defined as any discrepancy between the category assigned using a radiographic view and the category assigned using a CT view; this change in displacement category represents a substantial change in the percent displacement or in the ability to assign a category. The values are given as the percentage of measurements for which the displacement category disagreed.

To improve the assessment of patients with this injury, we developed methodology for surgeons to reproducibly measure displacement on radiographs and assess the ability of measurements on radiographs to correspond to the displacement assessed with a CT scan. The main finding in this study is that by utilizing the corresponding point measurement methodology, experienced clinicians can agree on displacement with almost perfect reliability using anteroposterior and EO radiographs and CT scans. In addition, the axial view has substantial reliability. Studies investigating the reliability of radiographs for assessing the displacement of medial epicondyle fractures have produced varied results[7,19,31]. Pappas et al.[19] evaluated the interobserver reliability of measurements from raters at various training levels and noted the overall interobserver ICC for measurements to be 0.80 using anteroposterior radiographs and 0.62 using oblique radiographs. In 2015, Souder et al.[23] introduced the axial view. In their cadaveric study, they found almost perfect reliability (ICC = 0.974) with a mean measurement error within 2 mm of the true displacement. However, that was a controlled laboratory study with idealized images and may not represent real-world performance. Our study used 6 complete sets of images obtained from patients as part of their usual clinical care. By employing a standardized corresponding point measurement methodology, our study found that absolute fragment displacement can be measured on both the anteroposterior radiographs (ICC = 0.944) and the EO radiographs (ICC = 0.975) with almost perfect reliability between raters. The improved reliability for the anteroposterior and EO views compared with that reported by Pappas et al.[19] may be a result of the corresponding point methodology utilized in this study. However, the experience of the clinicians performing the

TABLE IV Treatment Change When Recommendations Between Radiographic and CT Methods Disagreed*

Radiographic View and Treatment Change with CT	Axial CT†	3D Horizontal CT†	3D Vertical CT†	Mean
Anteroposterior				
Operative to nonoperative	22%	29%	16%	23%
Nonoperative to operative	78%	71%	84%	77%
Axial				
Operative to nonoperative	59%	56%	50%	55%
Nonoperative to operative	41%	44%	50%	45%
EO				
Operative to nonoperative	55%	50%	40%	49%
Nonoperative to operative	45%	50%	60%	51%
IO				
Operative to nonoperative	50%	55%	50%	52%
Nonoperative to operative	50%	45%	50%	48%
Lateral				
Operative to nonoperative	60%	50%	40%	50%
Nonoperative to operative	40%	50%	60%	50%

*The direction of change for each subcategory is from the recommendation after looking at the radiographic view to the recommendation after looking at the CT view. †The values are given as the percentage of cases for which the indicated pair of treatment recommendations differed.

measurements may also partially account for this discrepancy. Pappas et al.[19] included subjects of varying levels of experience and noted a trend toward more reliable measurements with more experienced clinicians. For the axial view, we found an ICC of 0.775, corresponding only to substantial interobserver reliability. The lower reliability noted here relative to 2 previous cadaveric studies[23,32] likely represents the difference between the less than perfect real-world imaging with overlying soft-tissue swelling and a controlled cadaveric study.

Once a measurement is deemed reliable, it should also reflect the true degree of separation between the 2 measurement points. Cadaveric studies have assessed the accuracy of anteroposterior, oblique, and axial views. However, the real-world accuracy of these views has not been reported. Gottschalk et al.[31] reported excellent interobserver agreement using anteroposterior and IO views to evaluate an adult cadaveric arm model with 5, 10, and 15 mm of anterior displacement. To improve their accuracy, they performed an additional trigonometric assessment based on the exact angle of the radiograph. The accuracy of the axial view has been investigated by both Souder et al.[23] and Cao et al.[32]. Both groups concluded that the axial view more accurately estimated the true displacement when compared with the anteroposterior view, with Cao et al.[32] noting a mean bias of 0.59 mm with a lower limit of agreement of −2.02 mm and an upper limit of agreement of 3.02 mm. We used rater measurements from the accompanying CT scan as the preferred method for assessing fracture displacement. We also found low mean biases (<1 mm) for the anteroposterior, axial, and EO views. However, the limits of agreement were much greater in relationship to the mean bias, in the ±5 to 6-mm range, for all of the views. This means that a measurement made on radiographs in the clinical setting could overestimate or underestimate the CT-based measurement by as much as 5 to 6 mm. In a fracture pattern in which the mean displacement is usually <15 mm and the threshold for operative treatment is often <5 mm, overestimating or underestimating displacement by 5 to 6 mm is likely to give a very different impression of the injury.

For assessment tools that are reliable and accurate, their ability to influence a treatment decision lies at the heart of their clinical utility. We found that management decisions differed almost 50% of the time when using CT imaging compared with the axial radiograph. Management decisions differed less often for the anteroposterior view (29%) compared with the EO view (41%) or the axial view (47%). However, these discrepancies are still meaningful in clinical practice. This suggests that experienced clinicians would change their recommendation for treatment one-third to one-half of the time if a CT scan was performed. Given the observation that, when surgeons switched treatment based on the anteroposterior view, 77% of those treatment recommendations changed from nonoperative using the anteroposterior view to operative using CT, the CT scan may provide a more complete picture of the fracture that spurs that change in treatment. This is especially interesting given that this group of treating surgeons had an overall low concordance for treatment recommendations based on radiographs. Further suggestions for clinical algorithms and conducting medial epicondyle research are outlined in the Appendix.

Study strengths included the large, homogenous group of raters and the fact that the imaging studies were performed in the evaluation of pediatric patients with medial epicondyle fractures in a live clinical setting. Nevertheless, this study included some limitations. As the raters were all fellowship-trained pediatric orthopaedic surgeons, the generalizability of these results may have been limited. Logistical constraints also limited our ability to assess the surgeons a second time, so intraobserver reliability could not be assessed. In addition, consistent patient positioning was not confirmed by the study investigators. Therefore, given the sample size, a systematic bias may have been introduced by less-than-perfect images, specifically regarding the degree of obliquity on the IO and EO radiographs. It is also possible that the fracture fragments could move slightly with changes in elbow positioning during radiography and between radiography and CT acquisition. We attempted to pick cases with a complete set of ideal images available for review; however, in doing so, we excluded many cases with less-than-ideal images. This selection process may have inadvertently introduced a bias in the type of fracture patterns assessed, but it also highlights the fact that obtaining ideal radiographs in the setting of an acute elbow injury is difficult and time-consuming. Of note, identifying cases with an appropriately obtained axial view of the elbow was especially difficult, hinting at the difficulty of positioning for this specialized view in the setting of a traumatic injury. Although simply proceeding with a CT scan may be seen like a viable alternative to obtaining additional specialized views, it comes at a cost of greater radiation exposure and it is still unclear what information on the CT scan should be used for decision-making. Lastly, there were no standardized criteria for treatment recommendations and the surgical indications used by the individual raters were not recorded. Therefore, recommendations with regard to the threshold of displacement that should be an indication for a surgical procedure are beyond the scope of this study.

In conclusion, surgeons can reliably measure fracture displacement using anteroposterior, EO, and axial radiographic views when a corresponding point measurement method is used. CT-based measurements are also reliable. However, although there is an overall low mean bias of <1 mm when comparing fracture displacement using radiographs, including the axial view, with CT-based methods, the measurements can differ by up to 5 to 6 mm. Thus, if radiographic assessment clearly indicates a patient for surgical treatment, a CT is unlikely to further inform that decision. However, a CT scan may be useful when precise fracture characterization is needed for patient management decisions or research cohort-matching purposes.

Appendix

eA Supporting material provided by the authors is posted with the online version of this article as a data supplement at jbjs.org (http://links.lww.com/JBJSOA/A439). ■

Ryan H. Guzek, MD[1]
Kathleen Harwood[2]
David Isaacs[1]
Divya Talwar, PhD[1]
Eric W. Edmonds, MD[3]
Peter D. Fabricant, MD, MPH[4]
V. Elaine Joughin, MD, FRCSC[5]
Kevin H. Latz, MD[6]
Stephanie W. Mayer, MD[7]
Scott McKay, MD[8,9]
Donna M. Pacicca, MD[6]
Michael Saper, DO[10]
J. Todd R. Lawrence, MD, PhD[1]

[1]The Children's Hospital of Philadelphia, Philadelphia, Pennsylvania

[2]New York Medical College, Valhalla, New York

[3]Rady Children's Hospital and Health Center, San Diego, California

[4]Hospital for Special Surgery, New York, NY

[5]Alberta Children's Hospital, Calgary, Alberta, Canada

[6]Children's Mercy Hospital, Kansas City, Missouri

[7]University of Colorado, Aurora, Colorado

[8]Texas Children's Hospital, Houston, Texas

[9]Baylor College of Medicine, Houston, Texas

[10]Seattle Children's Hospital, Seattle, Washington

Email for corresponding author: lawrencej@chop.edu

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