Use of Digital Tomosynthesis in Assessing Accurate Medial Epicondyle Fracture Displacement as Compared With Conventional Radiography and Computed Tomography

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Introduction: Medial epicondyle fracture displacement is notoriously difficult to determine on conventional radiography, and follow-up computed tomography (CT) is often obtained to measure precise displacement. Another option for fracture characterization is digital tomosynthesis (DT), a technology providing high in-plane resolution of bony anatomy by acquiring multiple low-dose images in a linear arc. Advantages of DT include lower radiation exposure and lower cost than CT, rapid image acquisition, and a similar patient experience to conventional radiography. The digital application of tomosynthesis is relatively new and is integrated as an add-on feature with modern radiography equipment. This study compares DT, CT and conventional radiography for measurement accuracy in medial epicondyle fractures with the goal of determining relative accuracy in measuring medial epicondyle fracture displacement.

Methods: Medial epicondyle fractures were created in 5 cadaveric elbow specimens. Each specimen was imaged with conventional radiography, DT, and CT. True displacement measured by digital calipers was compared with "measured" displacement for each image acquisition. CT images included axial, sagittal, and coronal reformats. DT images of the elbow included anteroposterior (AP) longitudinal and transverse, lateral longitudinal and transverse, and axial longitudinal and transverse. Conventional radiographs included AP, lateral, and axial distal humerus images. Four physicians reviewed all images 3 months later. Each reviewer independently measured maximum apparent fracture displacement to the nearest 0.1 mm. Measurement accuracy was calculated as percent difference [(measured displacement−actual displacement)/actual displacement] for each acquisition. Mean, median, and SD for measurement accuracy were calculated. Two-tailed paired *t* tests were performed on each acquisition to compare the measurement accuracy.

Results: Compared with conventional radiographs, accuracy of DT was superior in AP longitudinal ($P=0.03$), AP transverse ($P=0.01$), axial longitudinal ($P=0.0001$), and axial transverse projections ($P=0.001$). Accuracy of CT was superior to conventional radiography in the AP projection ($P=0.03$), but was equivalent in the axial projection ($P=0.9$). Accuracy of CT was similar to DT in AP longitudinal ($P=0.6$), AP transverse ($P=0.5$), and axial longitudinal projections ($P=0.07$). Accuracy of DT in the axial transverse projection was superior to CT ($P=0.03$).

Conclusion: DT is more accurate than conventional radiography (both AP and axial views) and as accurate as CT in assessing millimeters of displacement of medial epicondyle fracture fragments.

Level of Evidence: Level IV—diagnostic study.

Key Words: digital tomography, digital tomosynthesis, medial epicondyle fracture, displacement, pediatric fracture, cadaver radiograph, computed tomography

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Pediatric elbow fractures are frequent injuries, affecting ~3/1000 children per year.[1] Medial epicondyle fractures account for about 7% to 12% of all pediatric elbow fractures and typically occur in children ages 9 to 14.[2–5] Controversy surrounds the decision of whether or not to operate, with historic accounts of good outcomes from nonoperative treatment even in the setting of significant displacement and fibrous nonunion.[6–10]

While absolute indications for surgical management (ie, open fracture, ulnar nerve dysfunction and intra-articular fragment entrapment) are straightforward,[11,12] relative indications (eg, valgus instability, limb dominance, participation in gymnastics or baseball pitching, and amount of fragment displacement) are less clear.

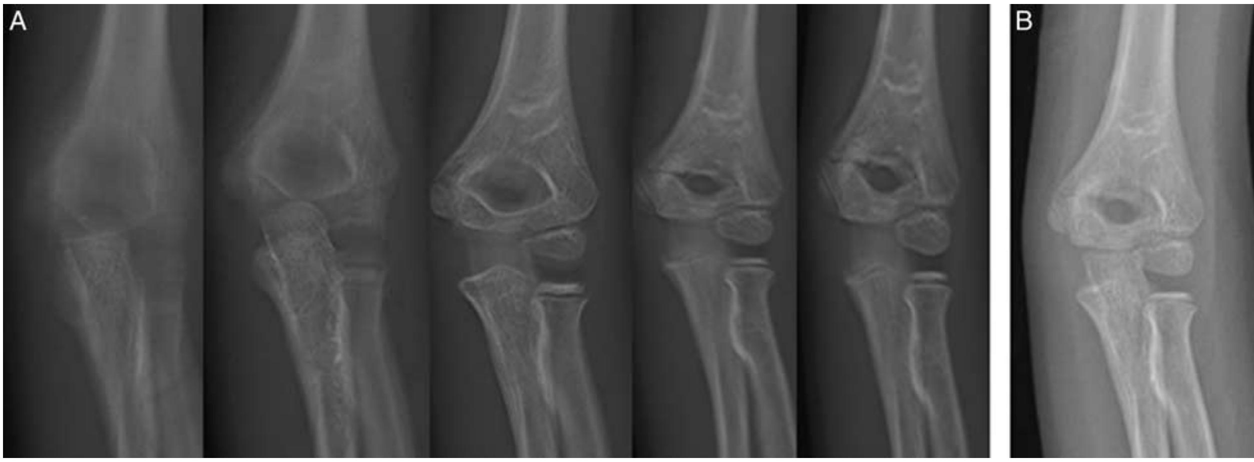

FIGURE 1. Subset of anteroposterior longitudinal digital tomosynthesis images illustrating detailed bony anatomy, each image at different depth (A). Last 2 images highlight fracture arc of supracondylar humerus fracture, which is less obvious on corresponding conventional radiograph (B).

There is no universally accepted guideline of how much displacement warrants surgical fixation, with reported thresholds for surgery ranging from 2 to 20 mm.[6,8,13–20]

Unfortunately, medial epicondyle fracture displacement is notoriously difficult to evaluate on conventional radiographs, spurring a breadth of literature devoted to determining true displacement.[2,21–23] Due to the shortcomings of conventional radiography, which has poor intraobserver and interobserver reliability,[24,25] computed tomography (CT) has become the preferred method for evaluating fracture displacement to help decide whether surgical management is warranted.[21] A CT scan, however, has a high cost, added logistical complexity and, more importantly, a higher radiation dose, and thus is not an ideal study in the pediatric population. Digital tomosynthesis (DT) is a technology that was developed in the early 1980s but was mainly limited to research and clinical applications in mammography.[26] More recently, DT has become a standard option on modern radiology imaging machines, is FDA approved for clinical use including musculoskeletal imaging, and as such is becoming more widely available with over 600 installations in the United States.[27] DT provides in-plane high-resolution slices (Fig. 1) of bony anatomy using multiple low-dose exposures from an x-ray source moving across an arc trajectory aimed at a stationary digital detector in a single sweep (VolumeRAD Digital Tomosynthesis, GE Healthcare).[28] This can be done at the same time and on the same machine as conventional radiography. The output is a scout image (traditional radiograph) plus a series of focus planes that one can scroll through with high in-plane resolution. These images can be measured with standard imaging software measurement tools. To systematically evaluate the value of DT in assessing displacement of medial epicondyle fractures, we designed a cadaver based study to compare true vs image-measured displacement of medial epicondyle fractures in digital tomography as well as standard radiographs and CT.

METHODS

A Biologic Use Authorization was obtained at our institution to use fresh-frozen cadaveric upper extremity specimens in our clinical radiology suite. The specimens used had no history of elbow injury or arthritis. A total of 5 upper extremity specimens were utilized. The specimens were obtained from our university's Willed Body Program. Soft tissues were dissected and a medial epicondyle fracture was created by a pediatric orthopaedic surgeon under direct visualization using an osteotome, taking care to simulate the relatively posterior and oblique orientation typical of a medial epicondyle fracture.[23] Each fracture fragment was displaced anteriorly and inferiorly to varying degrees and secured in place with 2 stout radiolucent sutures to maintain roughly constant position throughout the imaging process. More secure Kirschner-wire (k-wire) fixation would have been ideal but produced too much imaging artifact. The specimens were then transported to our clinic area for imaging with conventional radiography, DT, and CT. DT image acquisitions are referenced according to Zapala et al[29] which describes DT with respect to static projection [anteroposterior (AP), lateral, or axial], acquisition sweep direction (longitudinal or transverse relative to the long axis of the humerus) and focal point (distal humerus). Our DT acquisitions included AP longitudinal distal humerus, AP transverse distal humerus, lateral longitudinal distal humerus, lateral transverse distal humerus, axial longitudinal distal humerus and axial transverse distal humerus (Fig. 2). The corresponding radiograph (AP, lateral, or axial) was taken at the same time as each DT acquisition (Fig. 3). A CT scan was also obtained for each specimen with axial, sagittal, and coronal reformats. Due to the subtle fragment motion from manipulating the arm for imaging (despite suture fixation), the "true" fracture displacement was measured on the specimen by direct visualization with digital precision calipers to the nearest 0.1 mm before every single radiographic, DT, or CT acquisition. Given constraints on time and x-ray suite availability, not all specimens had all imaging acquisitions obtained (Table 1). All conventional

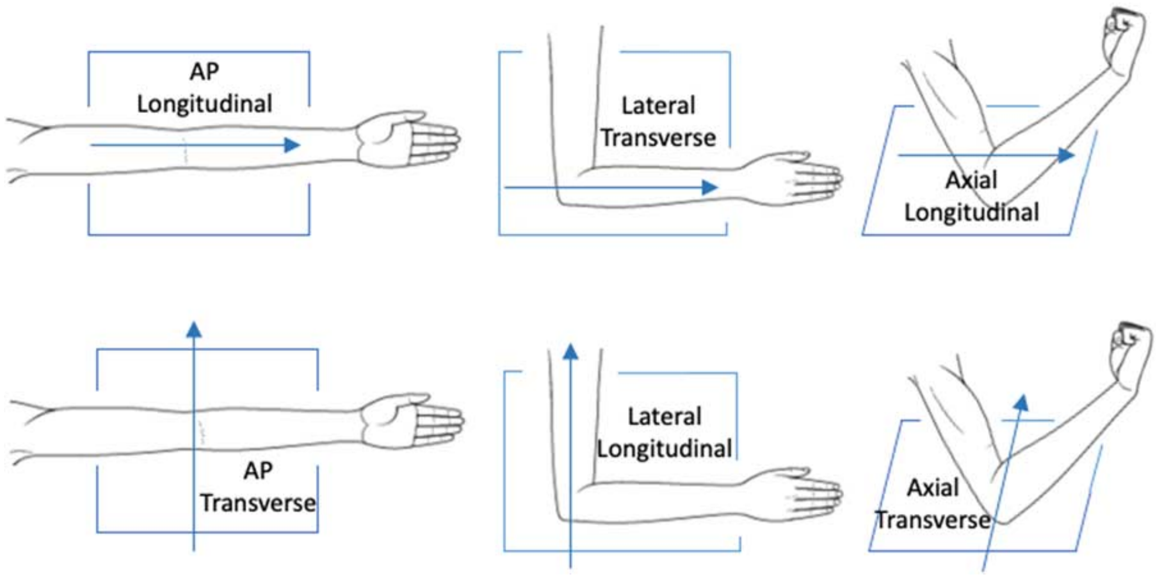

FIGURE 2. Digital tomosynthesis acquisition sequences. AP, lateral and axial orientation with longitudinal or transverse sweep directions (relative to distal humerus). Sweep direction denoted by arrow. AP indicates anteroposterior.

radiographs, DT, and CT images were then viewed 3 months later by 4 physicians (1 pediatric orthopaedic surgeon, 3 pediatric musculoskeletal radiologists) who each measured maximum apparent cortical displacement of the medial epicondyle fracture to nearest 0.1 mm on AGFA Impax PACS software (version 6.7.0.3502 2019). Radiographs were measured separately for each plane (ie, AP, lateral, axial), DT acquisitions were measured separately for each plane/direction combination (ie, AP longitudinal, AP transverse, axial longitudinal, axial transverse), while CT scan was measured on any of the reformatted planes (axial, sagittal, coronal). We did not utilize CT 3-dimensional reconstructions.

Measurement accuracy was calculated as percent difference [(measured displacement−actual displacement)/actual displacement] for each image projection. For each projection, the mean, median, and SD for measurement accuracy were calculated. Two-tailed paired t tests were performed on each projection to compare the measurement accuracy of conventional

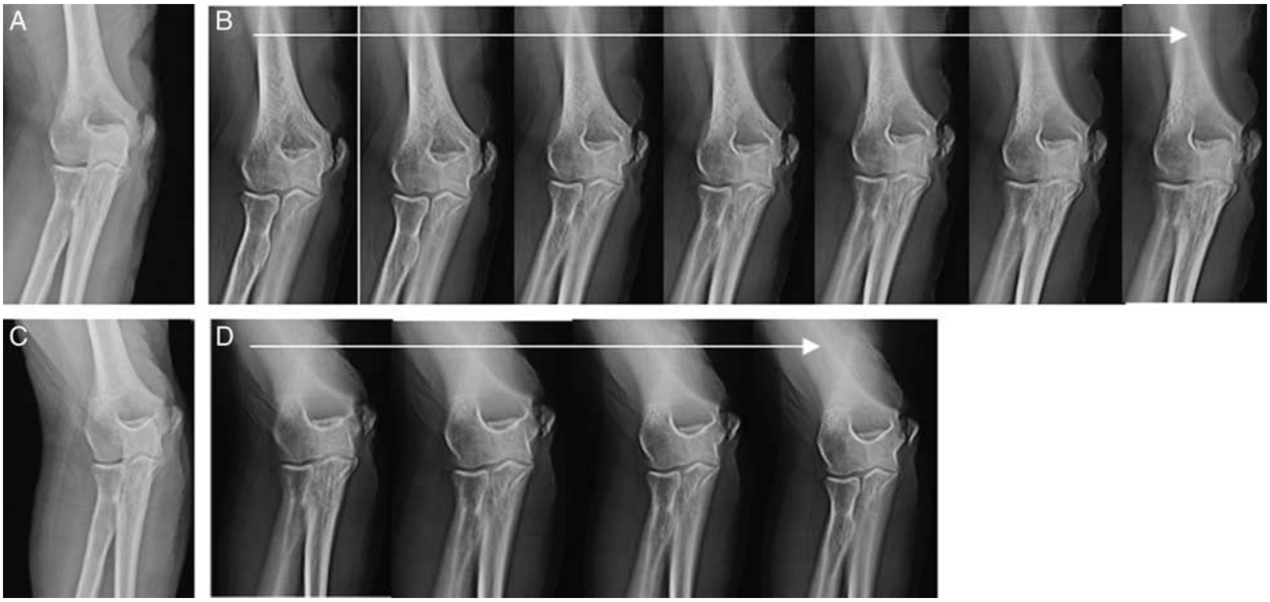

FIGURE 3. AP elbow x-ray (A) compared with output sequence of AP transverse digital tomosynthesis images (B). Axial elbow x-ray (C) compared with output sequence of axial transverse digital tomosynthesis images (D). AP indicates anteroposterior.

TABLE 1. Comparison of Measurement Accuracy Between Imaging Modalities

Acquisition	Modality	No. Specimens Imaged	No. Measurements	Mean Measurement Accuracy	Median Accuracy	SD	XR vs. DT (*P*)	XR vs. CT (*P*)	DT vs. CT (*P*)
AP	XR	4	16	−0.26	−0.24	0.16	0.03	0.03	0.63
AP longitudinal	DT	4	16	−0.14	−0.15	0.16			
Axial/coronal/ sagittal	CT	4	16	−0.11	−0.09	0.20			
AP	XR	2	8	−0.10	−0.11	0.08	0.01	0.38	0.45
AP transverse	DT	2	8	0.02	0.05	0.11			
Axial/coronal/ sagittal	CT	2	8	−0.04	−0.04	0.16			
Axial	XR	4	16	−0.12	−0.08	0.14	< 0.001	0.88	0.07
Axial longitudinal	DT	4	16	0.00	0.00	0.11			
Axial/coronal/ sagittal	CT	4	16	−0.11	−0.09	0.20			
Axial	XR	5	20	−0.08	−0.10	0.13	0.001	0.65	0.03
Axial transverse	DT	5	20	0.04	0.02	0.16			
Axial/coronal/ sagittal	CT	5	20	−0.11	−0.10	0.20			

AP indicates anteroposterior; CT, computed tomography; DT, digital tomosynthesis; XR, x-ray, conventional radiography.

radiographs and DT. A 2 sample *t* test with equal variance was used to compare CT measurement accuracy to that of both conventional radiographs and DT. *P* values < 0.05 were considered to be statistically significant.

RESULTS

Five cadaveric upper extremity specimens underwent the imaging acquisitions as detailed in Table 1. Displacement was able to be measured on all AP and axial images for radiographs and DT. There were 19 lateral radiographs and 19 lateral DT acquisitions obtained, with 4 reviewers measuring each one, yielding 76 opportunities for measurement for each modality. Despite several lateral DT acquisitions that showed fracture displacement with excellent clarity (Fig. 4), reviewers could not reliably assess fracture displacement in 24/76 measurement opportunities for lateral DT. Reviewers were unable to measure fracture displacement in 72/76 measurement opportunities for lateral radiographs. Lateral views of radiographs and DT, therefore, were not included in any further analysis given the unreliability of lateral views for accurately measuring displacement. Table 1 compares measurement accuracy in AP and axial planes of the 3 imaging modalities:

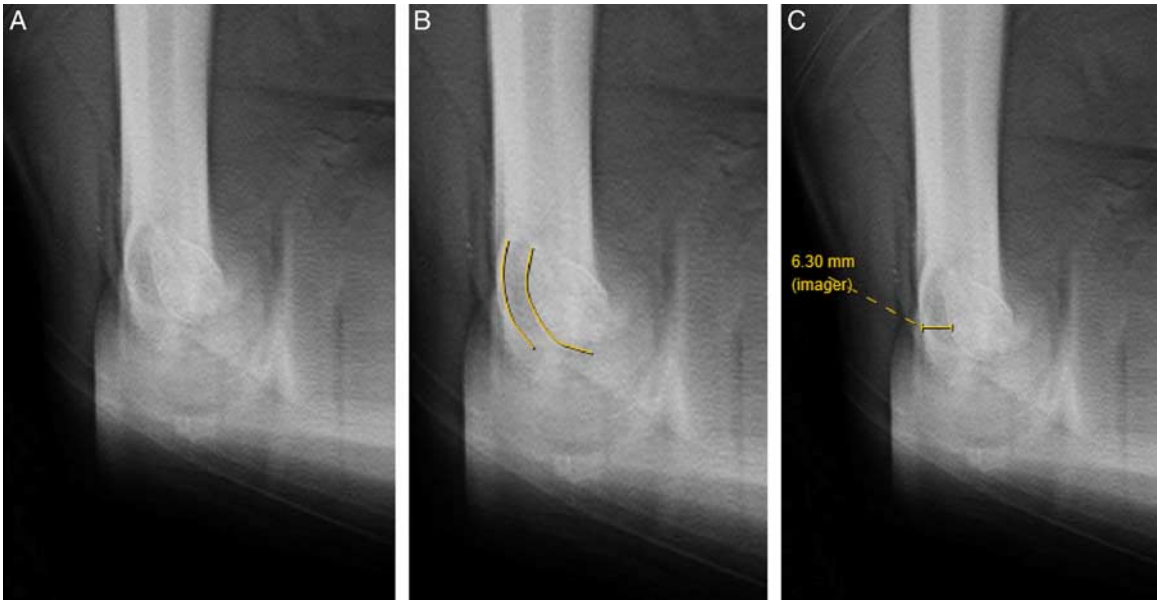

FIGURE 4. Medial most images of lateral longitudinal digital tomosynthesis image sequence demonstrating fracture fragment (A) and clear delineation of displacement (B), with associated measurement (C).

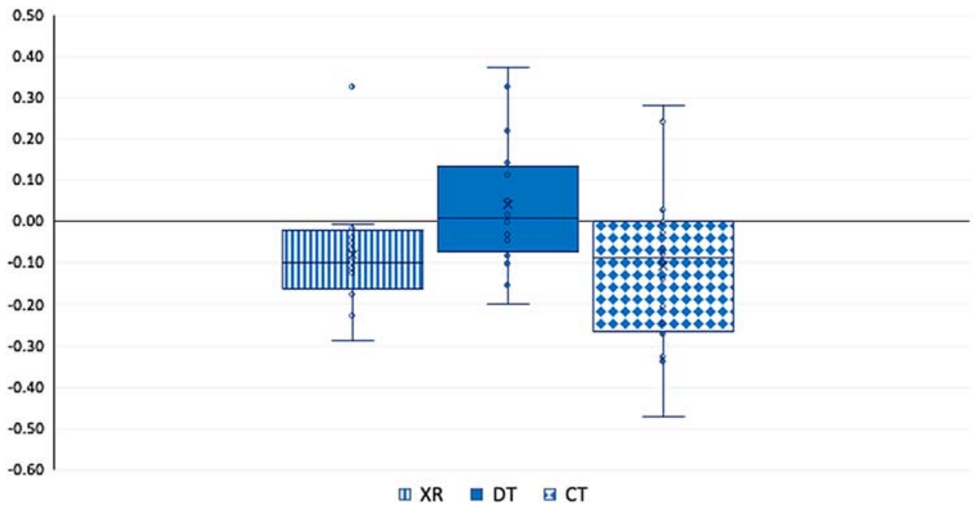

FIGURE 5. Box-Whisker plot displaying accuracy of axial radiographs (XR) versus axial transverse digital tomosynthesis (DT) versus multiplanar computed tomography (CT). *Y*-axis, percent difference = [(measured displacement–actual displacement)/actual displacement]. °, Individual measurement accuracy measurements. Numbers closer to 0 are more accurate. x, Mean accuracy; center line = median accuracy; box defines 25th to 75th percentile, outer whiskers define 0 to 100 percentile.

radiographs, DT, and multiplanar CT. Compared with corresponding radiographs, accuracy of DT was superior in AP longitudinal ($P=0.0307$), AP transverse ($P=0.0106$), axial longitudinal ($P=0.0001$), and axial transverse projections ($P=0.001$). Accuracy of multiplanar CT scan was superior to AP radiographs ($P=0.026$), but was not significantly different to axial radiographs ($P=0.876$). Multiplanar CT was not significantly different in accuracy to DT in AP longitudinal ($P=0.629$), AP transverse ($P=0.455$) and axial longitudinal ($P=0.0703$) projections. DT in the axial transverse projection was superior to multiplanar CT in accuracy ($P=0.031$). Box-whisker plot shows the differences in accuracy between modalities, and is shown in Figure 5.

DISCUSSION

Out study indicates that DT, which has previously been demonstrated to increase diagnostic accuracy and confidence in assessing pediatric elbow fractures,[29,30] is an accurate way to reliably measure fracture displacement in medial epicondyle fractures. In the management of medial epicondyle fractures in children, most surgeons agree that displacement is an important factor to consider in deciding whether surgical fixation is warranted, but there is a wide range of tolerance for fracture displacement between surgeons. Regardless of what one's threshold for surgery is, it is generally accepted that millimeters matter.

Limitations of accuracy and consistency of conventional radiographs for measuring displacement in this fracture have been widely publicized.[25] The difficulty in measurement is due to multiple developmental ossification centers, the obliquity of the plane of the medial epicondyle apophysis, and direction of fracture displacement which is generally in the AP, axial, and sagittal planes. A 2013 cadaveric study sought to improve technique with an internal oblique view, yet there was only modest success in accuracy and measurements have to be adjusted by a multiplicative factor to account for trigonometry.[24] The axial distal humerus radiographic view has also been touted as a more accurate way of measuring displacement compared with the AP radiographic view[22,23,27] although it may not be a familiar position for a radiology technician. We used the axial view in our analysis due to its demonstrated performance and still found DT to be superior in accuracy. Moreover, traditional standard AP positioning using DT was found to be as accurate as CT which may obviate the need for the less familiar axial positioning. Other authors emphasize that obtaining a reliable measurement is paramount to successful treatment, and they assert that CT overcomes the problem of conventional radiographs and delivers more reliable and accurate results.[21] While a CT scan does offer a more reliable measurement of displacement compared with conventional radiographs using traditional projections, it comes at added cost, with added logistics and at a substantially higher radiation dose than standard radiographs. A newer technology, DT, holds promise of multiple uses in orthopaedic surgery, given that it is fast, relatively inexpensive and low radiation compared with CT. Radiation associated with DT is ~6 to 9 times the dose of a conventional radiograph (390 μGy compared with 65 μGy) but ~25 to 55 times less dose than a CT scan which is about 14.6 mGy.[27,31] DT is also relatively inexpensive, billed as CPT code 76100 (0.58 WRVU) with a cost of about $900 at our hospital, compared with a 3 view elbow radiograph (CPT code 73080, 0.17 WRVU) which costs about $1000 and an elbow CT (CPT code 73200, WRVU 1) which costs about $7000. In addition, DT can be done at the same time as the radiograph and takes an additional 6 seconds, as opposed to CT which has the added logistics of requiring a separate imaging suite and often a separate appointment. Our results suggest that DT may provide an optimal way of obtaining a highly accurate measurement of fracture displacement for medial epicondyle fractures without the need for the added complexity of a CT scan and with the use of standard patient positioning.

We found that the most accurate way to measure displacement was on the axial longitudinal or axial transverse acquisition. While the axial DT views are the most accurate, the AP DT views are also statistically as accurate as CT and may be an easier acquisition to obtain, as it is likely to be more familiar positioning to radiology technicians. This test can be done simply, at time of initial radiographs, and may obviate the need to send a child for CT at added time, care coordination, cost, and radiation.

There are some notable limitations to our study. Obviously, there is a limit to the fidelity of cadaveric fracture simulation. Elbow specimens were skeletally mature though, as the fracture occurs through the apophysis, the lack of apophysis is not radiographically imperative and the fracture plane was created according to typical anatomic patterns that occur in this injury.[23] An adult elbow specimen was therefore felt to be relatively high fidelity for a medial epicondyle fracture model and has precedent in the literature for similar cadaveric studies.[22,24] Ideally, we would have more specimens and would have obtained all acquisition sequences for all specimens, but cadaveric arms and time in the radiology suite are valuable, limited resources. Furthermore, while the osteotomy was made by an experienced pediatric orthopaedist, according to evidence based technique,[23] it is certainly possible for fracture morphology in individual patients to differ from our specimens' fracture morphology. That said, we believe that the AP or axial DT reformatted slices will still capture enough detail to make accurate measurements even if slightly off plane. CT does have the advantage of providing multiplanar visualization but comes with the added costs of radiation, time, and money that we have described. We would have preferred to have the fragment stabilized with a k-wire to make the displacement consistent for each specimen throughout imaging, however a k-wire produced too much artifact and altered our ability to measure displacement. We adapted to this by performing caliper measurements immediately before each separate imaging acquisition.

We anticipate that this study will translate well to clinical practice. We use digital tomography regularly at our institution for evaluation of pediatric orthopaedic trauma, mainly in elbow, wrist, and ankle imaging. Anecdotally and in peer reviewed studies,[29,30] it has been found to be extremely helpful in diagnosis and management of pediatric fractures.

In conclusion, we found the accuracy of DT superior to conventional radiography for the measurement of medial epicondyle fracture displacement. No appreciable difference in the accuracy was found between DT and CT. While DT and CT both provide multiplanar imaging for exquisite depiction of fracture patterns that help in operative planning, DT holds promise in its burgeoning use in orthopaedic trauma as a rapid and cost-effective method at a fraction of the radiation dose.

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