Cone beam computed tomography increases diagnostic confidence in radiographically occult radiocarpal fractures

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Aims and objectives

Fractures of the wrist and hand are the reason for 1.5% of all emergency department visits\(^1\). Less than 20% of patients with a clinically suspected scaphoid fracture have a true fracture \(^2\). In the acute setting 5-20% of scaphoid fractures can be missed on initial radiographs\(^3\).

Plain radiography may be limited by superposition of anatomical structures, suboptimal positioning and technique, and suboptimal patient cooperation in emergency settings \(^4\). Failure to immobilise a wrist with a fracture can lead to complications such as non-union, avascular necrosis, development of carpal instability and osteoarthritis \(^5, 6\). Conversely, in the majority of cases where no fracture has occurred, unnecessary immobilisation can lead to overtreatment, increased healthcare costs and loss of productivity for the patient\(^7\).

It is common practice to immobilise the wrist until the probability of a true fracture being present, through imaging or clinical follow up, is deemed acceptably low. However recent cost effectiveness studies comparing empiric immobilisation to immediate MRI or MDCT in the setting of negative radiographs, found immediate advanced imaging to be a better choice for reducing costs and morbidity\(^8, 9\).

CBCT creates high resolution scans using a single 210 degree rotation of conical beam which falls on a flat-panel detector rather than a helically rotating fan shaped beam on a linear multi-detector used in conventional CT. The advantages of this technology include higher spatial resolution, reduction of metal artefacts, portability and low radiation dose\(^10, 11, 12\). The dose of CBCT of the wrist has been measured in a direct comparison as 3.6 times less than the dose from MDCT and 2.4 times more than the dose from AP and lateral projection wrist radiographs\(^13\).

CBCT has been shown in several studies to be more accurate than conventional radiography for the diagnosis of fractures of small bones as well as being faster to perform and yielding more diagnostic information\(^12, 14, 15\).

We aimed to evaluate the diagnostic value of CBCT for radiocarpal fractures that are not visible on standard radiographs.
Fig. 1: Principle of CBCT and MDCT. a) In CBCT, cone-shaped X-ray beam reaches a flat detector after a single rotation of the gantry around the patient. b) In MDCT, narrowly collimated, fan-shaped beam and multiple linear detectors rotate around the patient to acquire multiple image sections per rotation. In both techniques volumetric images are reconstructed into a 3-D volume dataset of images.

Methods and materials

Patients and inclusion/exclusion criteria

In July 2017 the imaging protocol in our hospital was changed for patients with acute wrist trauma to include a CBCT of the wrist in patients who had negative radiographs at initial evaluation and persistent clinical concern for a radiographically occult radiocarpal fracture. This scan was performed simultaneously with radiographs at time of follow up review in the orthopaedic clinic, usually 7-14 days after the initial trauma.

If CBCT showed a fracture which corresponded to a point of clinical tenderness, the patient was considered to have a fracture and treated as such. If neither radiography or CBCT showed a fracture repeat clinical examination was performed. If no fracture was suspected at this point the patient was discharged. If there was ongoing concern for fracture, immobilisation with repeat examination and MRI was arranged.

A retrospective review was performed from July 2017 to February 2018 of all patients who underwent CBCT for suspected occult fracture of the radiocarpal bones.

Patients were excluded if they met any of the following criteria: less than 16 years of age, pregnancy, definite fracture on initial radiographs, CBCT performed more than 14 days after trauma, no clinical concern for fracture at follow up examination.

Imaging techniques

Radiographs - Radiographs in patients with a suspected distal radius fracture consisted of two images: Anteroposterior (AP) and lateral views of the wrist in the neutral position. Radiographs for suspected carpal fracture consisted of four images: AP and lateral views of the wrist in the neutral position and an oblique view and scaphoid view with 20-30 degree tube angulation in ulnar deviation.

CBCT - All CBCT images were obtained using a Planmed Verity extremity CBCT scanner (Planmed Oy, Helsinki, Finland). The patient’s hand was placed on a gantry within a 13cm x 16cm field of view. The examination was conducted using a 90kV and 36mA protocol. No iodine contrast was injected. Slice thickness was 0.2mm. Total scan acquisition time is approximately 36s, with approximately 1 minute of image processing time after the scan. A single coronal reconstruction was sent to PACS, and assessed using Multiplanar reconstruction (MPR).

Image Analysis
Evaluation took place under standardised viewing conditions on diagnostic reporting monitors. All images were independently reviewed by a junior radiologist (3 years experience) and senior radiologist (11 years experience). Each radiologist determined whether a fracture was present, if there was fracture displacement and if the fracture represented a chip or involved the body of the bone. Fracture displacement was defined as either gapping and/or translation of 1mm or greater at the cortical surface. A chip fracture was defined as a fracture involving cortex only, while a fracture extending through cortex into the trabeculae of the bone was defined as involving the body.

Statistical analysis

The sensitivity, specificity, negative predictive value, positive predictive value, accuracy, 95% confidence intervals, and kappa coefficient for inter-rater agreement were calculated using SPSS software (SPSS, Chicago, Ill, USA).
Results

Demographics

Between July 2017 and February 2018, CBCTs were performed on 269 patients. 103 were excluded as they were for evaluation of known fractures, post-operative imaging or chronic pain assessment. 166 scans were performed patients with suspected radiocarpal fractures after trauma despite no fracture visible on initial radiographs. 49 were excluded as CBCT was performed over 2 weeks after wrist trauma. 117 were performed within the predetermined time limit of 2 weeks for acute fracture. The median number of days from initial trauma to CBCT was 9. This patient group was 51.2% male with an average age of 41, median of 39 and range was 16-81. Right sided wrist fractures were significantly more common than left sided wrist fractures (P<0.001). The most commonly suspected fracture on the clinical request was of the scaphoid, listed as the bone of concern in 76.9%. Six CBCT studies were suboptimal (3 conducted with the wrist in a cast and 3 with motion artefact) but considered assessable by all reviewers.

Fracture identification

The results for detection of radiocarpal fractures are presented in Table 1. 59 (50.7%) of the 105 patients had an acute fracture identified on CBCT. 6 patients had more than one fracture with a total of 67 fractures identified.

The most commonly fractured bones were the distal radius (13) and trapezium (13), each accounting for 19.4% of fractures in the cohort. 16.4% were triquetral fractures and 13.4% were scaphoid fractures. Fig. 2 & 3

18 of the 117 patients had a non-specific cortical abnormality on initial radiographs. 7 of these correlated with acute fractures on CBCT, while 9 patients had no fracture on CBCT and 2 patients had an acute radiocarpal fracture diagnosed in a bone separate from the bone with the cortical abnormality.

Gold standard for the presence of a fracture was taken as clinical follow up with MRI in cases with persistent clinical concern for fracture in cases with negative CBCT and in cases with no focal pain at the site of reported fracture. 8 patients had follow up MRI which identified 1 scaphoid fracture which was not on CBCT. One patient also had scaphoid oedema without a fracture line on T1 sequence, deemed not to represent a fracture for this study. All fractures identified on CBCT corresponded clinically to fracture on examination.
CBCT had a sensitivity of 98.3% (95% CI: 91.1%-100%), specificity of 100% (95% CI: 93.7% to 100%), PPV of 100%, and NPV of 98.3% (95% CI: 89.1% to 100%). Accuracy was 99.1% (95% CI: 95.3%-100%). Table 2

**Inter-rater agreement for CBCT**

3 of the fractures identified on CBCT by the senior radiologist were not diagnosed by the junior radiologist. The agreement rate between the two radiologists was $K = 0.948$ (95% CI 0.89-1).

**Fracture Characterisation**

25 (37.3%) of fractures were characterised as displaced. 44 (65.7%) of fractures extended into the trabeculae of the injured bone while 23 (34.3%) involved only a cortical fragment. Comminution was identified in 8 (11.9%) fractures, of which none had identified fracture on radiographs.

**Retrospective radiograph review**

In cases where CBCT identified a fracture, the patient's radiographs were re-assessed to identify if the known fracture was visible in retrospect. When injured bone, site and size of fracture was known, fractures could be confidently identified in 17%, indeterminate cortical abnormalities were seen in 25.4% and no abnormality was present in 57.6%. Fig. 4

**Radiation Dose**

CBCT had a set DLP for the imaging protocol used, of 35.3mGy/cm. Median Dose Area Product (DAP) for combined radiographs was 0.36 mGy/cm².
Table 1: Table of number of occult fractures identified in each radiocarpal bone and the percentage of total fractures involving each bone.

<table>
<thead>
<tr>
<th>Bone</th>
<th>Number identified on CBCT</th>
<th>Percentage of total fractures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scaphoid</td>
<td>9</td>
<td>13.4</td>
</tr>
<tr>
<td>Trapezium</td>
<td>13</td>
<td>19.4</td>
</tr>
<tr>
<td>Distal radius</td>
<td>13</td>
<td>19.4</td>
</tr>
<tr>
<td>Triquetrum</td>
<td>11</td>
<td>16.4</td>
</tr>
<tr>
<td>Pisiform</td>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>Trapezoid</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Capitate</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Lunate</td>
<td>1</td>
<td>1.5</td>
</tr>
<tr>
<td>Hamate</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>1st MC</td>
<td>3</td>
<td>4.5</td>
</tr>
<tr>
<td>2nd MC</td>
<td>3</td>
<td>4.5</td>
</tr>
<tr>
<td>3rd MC</td>
<td>3</td>
<td>4.5</td>
</tr>
<tr>
<td>Ulnar styloid</td>
<td>1</td>
<td>1.5</td>
</tr>
<tr>
<td>Total</td>
<td>67</td>
<td></td>
</tr>
</tbody>
</table>

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Fig. 2: Comparison of coronal reconstruction of CBCT (Left) with plain radiograph (Right), demonstrating an undisplaced fracture through the waist of scaphoid which is occult on radiographs.
Fig. 3: Demonstration of 3D reconstruction of CBCT showing a displaced fracture of the volar ridge of trapezium which is occult on standard radiographs. Radiograph is presented for comparison.

Table 2: Sensitivity, Specificity, Positive Predictive Value, Negative Predictive value and Accuracy of CBCT scans on patients with clinical suspicion of radiographically occult radiocarpal fractures.

<table>
<thead>
<tr>
<th></th>
<th>Percent (%)</th>
<th>Confidence intervals (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensitivity</td>
<td>100</td>
<td>93-100</td>
</tr>
<tr>
<td>Specificity</td>
<td>98.3</td>
<td>91.1-99.9</td>
</tr>
<tr>
<td>Positive predictive value</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>Negative predictive value</td>
<td>98.3</td>
<td>89.1-99.7</td>
</tr>
<tr>
<td>Accuracy</td>
<td>99.2</td>
<td>95.3-99.9</td>
</tr>
</tbody>
</table>

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Fig. 4: Demonstration of a displaced fracture of pisiform which was identifiable on radiographs on retrospective review of radiographs, following diagnosis with CBCT.

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Conclusion

We found that CBCT is highly sensitive for acute radiocarpal fractures in patients with clinical suspicion for fracture despite negative radiographs. CBCT provides more accuracy and diagnostic information than radiographs at a low radiation dose. We believe it has a place in the diagnostic work-up in extremity trauma. It could replace MDCT and restrict the need for follow up MRI to only the most suspicious cases. If appropriate resources for interpretation were in place, CBCT could potentially replace radiographs as the first line imaging investigation for radiocarpal fractures.
Personal information

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References


