Dual-energy CT in the diagnosis of occult acute scaphoid injury: a direct comparison with MRI

Cheng Xie¹ · Sarim Ather¹ · Ramy Mansour² · Fergus Gleeson³ · Rajat Chowdhury²

Abstract

Objectives Scaphoid injuries occult on plain radiography often require further imaging for definitive diagnosis. We investigate the utility of dual-energy computed tomography (DECT) for the detection of acute bone marrow oedema and fracture of scaphoid compared to MRI.

Materials and methods Twenty patients who presented acutely (without prior injury) to the emergency department with clinically suspected occult scaphoid fracture and had MRI of the wrist were prospectively recruited to have DECT (GE Revolution CT). Material decomposition images of the water-calcium base pair were generated and assessed in conjunction with the monochromatic images to permit correlation of marrow signal changes with any cortical disruption for fracture confirmation. The assessment was performed by two musculoskeletal radiologists blinded from MRI results. The statistical difference of MRI and reviewers’ detection of acute bone oedema (1 = present, 0 = absent) was performed using the Friedman test (SPSS v.16).

Results MRI showed acute scaphoid fracture and/or bone marrow oedema in 14/20 patients of which 6 also had cortical disruption. On DECT, reviewer A identified oedema in 13 and cortical disruption in 10 patients while reviewer B identified oedema in 10 and cortical disruption in seven of the 14 MRI positive patients. No statistically significant difference in oedema detection on MRI and reviewers of DECT (p value 0.61) but DECT was more sensitive at detecting cortical disruption.

Conclusion DECT has the capability to detect acute scaphoid oedema in addition to cortical fractures. However, compared to MRI, DECT has lower contrast resolution and less sensitive in the detection of mild oedema.

Key Points
• Dual-energy CT is able to detect acute traumatic scaphoid marrow oedema.
• Dual-energy CT has greater detection rate of scaphoid fractures than MRI.
• Dual-energy CT is an alternative to MRI for occult scaphoid injury.

Keywords Wrist injuries · Scaphoid bone · Bone marrow · Edema · Radiography

Introduction

After a fall on to an outstretched hand (FOOSH), the scaphoid is the most frequently injured carpal bone and represents 2–3% of all fractures [1]. A timely diagnosis is important to reduce the risk of non-union, avascular necrosis, and subsequent comorbidities. When there is a convincing mechanism
of injury and clinical findings (anatomical snuffbox tenderness and/or pain on axial compression of the thumb), a plain radiograph is usually the initial step in the imaging workup. Plain radiography will detect the majority of scaphoid fractures. However, occult scaphoid fractures that are not detectable on the initial plain radiograph constitute up to 20% of scaphoid injuries [2]. At this stage, a number of second-line imaging options are available. The inconsistencies in the next line of investigation can lead to a delay in diagnosis and unnecessary treatment.

Currently, there is no consensus on the best second-line imaging modality to detect occult scaphoid fractures. The different diagnostic pathways after the patients’ first presentation can be a clinical follow-up and imaging with a repeat plain film, MRI, CT, or bone scan [3]. The many options available can further increase the time taken to exclude an occult scaphoid fracture.

At our institution, there is a high dependence on magnetic resonance imaging (MRI) to exclude the occult scaphoid fractures; however, due to limited availability, patients are usually unable to get a definitive diagnosis on the day of the injury. Studies in this area have shown that DECT has comparable results to MRI in identifying fractures and acute bone marrow oedema of the ankle, knee, hip, spine, and calcaneus [4–8]. A recent study and case report that focused on acute scaphoid bone marrow oedema also supports the use of DECT as an alternative to MRI [9, 10]. To our knowledge, all the current published work on DECT detection of bone marrow oedema has been conducted using the Siemens dual-source scanner and the virtual non-calcium (VNC) tool. Our study would be the first to investigate the use of GE Revolution CT, a single-source, rapid voltage switching DECT, and the water-calcium material decomposition images for this purpose. The objective of this study is to investigate the use of this specific DECT design in the detection of occult acute scaphoid fractures and associated bone marrow oedema in direct comparison with MRI.

Materials and methods

Ethical approval was obtained for this prospective study to investigate the use of DECT in patients, who have a clinically suspected scaphoid fracture, with direct correlation to their MRI. A total of 20 patients were recruited for this study.

Patient recruitment

Patients who present acutely to the emergency department with negative findings on plain radiograph but suspected to have an occult scaphoid fracture and referred for an MRI scan were recruited for this study. The patients’ MRI took place normally as per institution protocol, and all these patients were given information leaflets about the study after the MRI scan. The MRI scans were obtained with a 3-T HDx 750 (GE Medical Systems). The protocol included coronal T1 (slice thickness = 3 mm with 3 mm spacing, TR = 580 ms, TE = 12 ms, flip angle = 150), coronal STIR (slice thickness = 3 mm with 3-mm spacing, TR = 3000 ms, TE = 60 ms, flip angle = 150) and axial proton density fat-saturated sequences (slice thickness = 3 mm with 3 mm spacing, TR = 4400 ms, TE = 30 ms, flip angle = 150).

When the patients attended for their MRI scan, those who met the eligibility criteria (Table 1) were recruited by one of the study investigators. Formal written consent was taken from patients who agreed to take part in the study. Supplementary Figure 1 demonstrates the study flow and the usual patient pathway.

Image acquisition

DECT imaging was performed on a Revolution CT (GE Medical Systems), which uses a single x-ray source with rapid asynchronous switching of the energy levels to acquire high- and low-kVp images in an interleaved fashion and a single detector that registers information from both energies. The images for the current study were obtained using the following scan parameters: helical, rapid switch between tube voltages of 70 and 140 kVp in 0.5 ms; tube current, 260 mA; rotation time = 0.69 s; slice thickness, 0.625 mm; and slice interval, 0.625 mm.

| Table 1 Eligibility criteria                                      |
|------------------------------------------------------------------|
| **Inclusion criteria**                                           |
| Adult patients (age 18 and over)                                 |
| Males and females                                                |
| Clear mechanism of injury and clinically suspected acute scaphoid fracture |
| Negative findings on initial plain radiograph for acute scaphoid fracture |
| Patient is scheduled for a MRI examination.                      |
| **Exclusion criteria**                                           |
| Patients with scaphoid fractures identified on plain film        |
| Mechanism of injury unknown                                      |
| Previous scaphoid fracture to the injured wrist                  |
| Chronic inflammatory joint conditions – rheumatoid arthritis or connective tissue disorders |
| Suspicion of infective cause (ie septic arthritis)               |
| Extremely frail patients                                        |
| Pregnant patients                                                |
| Patients who are unable to provide informed consent             |
Image post-processing

Image post-processing was carried out using the Gemstone Spectral Imaging (GSI) viewer software on an Advanced Workstation Server 2.0 (AW 2.0; GE Healthcare). The high- and low-energy view data were processed using a projection-based material decomposition algorithm to generate material density images for the water-calcium base pairs. A colour overlay was added to the material density images for visual inspection. In addition, monochromatic images at 0.625-mm slice thickness and interval were also generated for fracture assessment using bone and soft-tissue kernels.

Image analysis

Qualitative assessment of the DECT images of the 20 participants was carried out by two experienced musculoskeletal consultant radiologists blinded to the MRI findings. They analysed the monochromatic images for the presence of cortical disruption and the material density images for the presence of bone marrow oedema.

Another musculoskeletal consultant radiologist reviewed the MRI images of the 20 participants for the presence of fracture and marrow oedema.

A study investigator not part of the imaging analysis process performed the data analysis. The statistical difference of the MRI against reviewers’ detection of acute bone oedema (1 = present, 0 = absent) was performed using the Friedman test (SPSS v.16). Statistical significance is taken as $p$ value $< 0.05$.

Results

A total of 20 patients were recruited for the study. This included 12 male and eight female patients, with a median age of 51 years (range, 20–76 years).

Supplementary Table 1 summarises the study findings including time from injury to presentation and imaging, the presence of scaphoid injury on MRI and DECT (for each reviewer independently), presence of non-scaphoid bony and soft-tissue injuries, and patient management.

The median time from the date of injury to the MRI scan was 13.5 days (range, 3–51 days). The median time from MRI to DECT was 6 days (range, 0–9 days) and 18 days from the date of injury (range, 6–57 days).

The MRI examination showed scaphoid bone marrow oedema in 14 of the 20 patients with corresponding fractures in six of the 14 patients. Other bony injuries were demonstrated in six patients and ligamentous injury in seven patients. Details of these additional injuries are summarised in Supplementary Table 1.

On the DECT examination, reviewer A identified 13 of the 14 patients who had acute scaphoid oedema on their corresponding MRI (Fig. 1), and reviewer B identified 10 of the 14 patients. These 10 cases either demonstrated focal scaphoid oedema centrally (Fig. 2) or they had oedema throughout the scaphoid (Fig. 3). The four cases in which reviewer B did not identify any scaphoid oedema included the one patient who reviewer A also reported as no scaphoid injury. In these four cases, the MRI showed either mild or subcortical scaphoid oedema (Fig. 4). Areas of cortical bone were not suppressed.

Fig. 1 Normal scaphoid. No acute scaphoid bone marrow oedema on the STIR sequence of the MRI (left), DECT with calcium/water filter (middle) and no fracture on the CT component (right).

Fig. 2 Focal and central acute scaphoid oedema. Both STIR sequence of the MRI (left) and DECT with calcium/water filter (middle) showed focal and central acute scaphoid oedema at the distal pole and waist of the scaphoid. The oedema is highlighted in gold on the DECT with calcium/water filter image. The CT component (right) did not show any fracture.
in the calcium subtracted images and could not be differenti-
ated from oedema.

The Friedman test was chosen to analyse for any statisti-
cally significant differences in scaphoid oedema detection be-
tween MRI and DECT (reviewers A and B). A patient with no
reported scaphoid oedema was assigned a score of 0, and a
patient with a reported presence of scaphoid oedema was
assigned a score of 1. The results showed a $p$ value of 0.61.

On the monochromatic component of the DECT examina-
tion, reviewer A identified all 6 fractures demonstrated on the
MRI and detected an additional four fractures that were not
demonstrated on the MRI. Reviewer B detected fractures in
seven patients. Overall, scaphoid injury (oedema or fracture)
was detected in all 14 MRI positive cases by reviewer A and
11 out of 14 MRI positive cases by reviewer B. Neither re-
viewer detected DECT scaphoid oedema in cases where there
was no oedema demonstrated on the MRI.

The reviewers also identified non-scaphoid bony injury in
six cases. This included a pisiform fracture not detected on
MRI. Widening of the scapholunate interspace was demon-
strated in the case where scapholunate injury was demon-
strated on the MRI. The old ulnar styloid fracture did not show any
bone marrow oedema on DECT.

**Discussion**

Currently, there are a number of second-line diagnostic imag-
ing investigations for occult fractures. Mallee et al (2015)
conducted a Cochrane systematic review that compared the
diagnostic accuracies of CT, MRI, and bone scan [11]. From
11 studies, 277 patients had CT, 221 had MRI, and 543 had a
bone scan for clinically suspected scaphoid fractures; the sen-
sitivity and specificity of CT were 0.72 and 0.99, of MRI 0.88
and 1.00, and of bone scan 0.99 and 0.86. The systematic
review concluded that bone scan had the highest diagnostic
accuracy, but it was the least preferred imaging examination
due to its invasiveness and relatively low specificity, which
would result in a larger number of unnecessary treatments.
Indirect comparison between CT and MRI showed compara-
ble diagnostic accuracies. The authors recommended either
CT or MRI as the second-line imaging modality depending
on availability. They also indicated that prospective studies
involving CT and MRI in the same patient population would
provide more valuable direct comparison between the diag-
nostic accuracies of two imaging options.

Subsequent to the above recommendations and our institu-
tion’s high dependence on MRI (one of the causes for the long
waiting period of up to 51 days as shown in our study results),
we proposed that DECT could be an alternative method for
the diagnosis of scaphoid fracture including the detection of
bone marrow oedema/bruising.

In our prospective study, we demonstrated that DECT
could be used to identify moderate to severe focal and diffuse
scaphoid bone marrow oedema. Apart from demonstrating
acute bone marrow oedema, DECT was also able to delineate
the small bony cortical disruptions to confirm the underlying
fracture, which can be difficult to detect on MRI. Our results

**Fig. 3** Diffuse acute scaphoid oedema. The STIR sequence of the MRI (left) and DECT with
calcium/water filter (middle) showed diffuse scaphoid oedema. The oedema is highlighted in gold
on the DECT with calcium/water filter image. The MRI also showed a distal pole fracture and
a bone cyst in the proximal pole, which were also identifiable on the CT component (right).

**Fig. 4** Mild acute scaphoid oedema. The STIR sequence of the MRI (left) showed a small peripheral area of oedema in the region of the waist of the
scaphoid. This was difficult to detect with confidence on the DECT with
calcium/water filter (middle) due to the ‘blooming’ artefact from the bony
cortex. No fracture seen on the CT component (right).
showed that DECT was limited in the detection of mild oedema seen on the MRI and/or oedema adjacent to the cortical surface due to lack of cortical bone oedema on the calcium subtracted images. Taking this limitation into account, statistically there was no significant difference in the detection of scaphoid bone marrow oedema between MRI and DECT. Scaphoid injury (oedema or fracture) was detected in all 14 MRI positive cases by reviewer A and 11 out of 14 MRI positive cases by reviewer B and the three cases where the injury was not detected by reviewer B were all treated conservatively indicating low clinical significance for failing to identify mild bone marrow oedema.

Although this is not the first study to use DECT to assess bone marrow oedema, it is currently the only published study that utilised the GE rapid voltage switching dual-energy CT (Revolution CT), and the water-calcium material decomposition images on using the Gemstone Spectral Imaging (GSI) viewer software for this purpose. The two recently published studies that investigated the diagnostic value of DECT in acute scaphoid and wrist injury both used the Siemens dual-source CT scanner and VNC reconstruction for the assessment of bone marrow oedema [9, 10]. Previous studies have also taken the same approach in the assessment of bone marrow oedema [4–8]. The results of these studies concluded that DECT is an alternative to MRI for identifying bone marrow oedema including in the setting of acute scaphoid injuries.

Our study highlights a significant limitation of the water-calcium material decomposition technique in that it fails to differentiate between cortical bone and oedema, reducing its sensitivity for the detection of subcortical oedema. This is a known limitation of the DECT non-calcium technique [12, 13] and different methods have been suggested to overcome this such as altering the calcium suppression parameters [14] and using water-cortical bone material decomposition pairing [15].

One of the other limitations of this study is the time interval between the MRI and DECT and time interval between the first presentation to the emergency department and the DECT. It took up to 9 days between the MRI and DECT and up to 57 days from date of injury to DECT (although in this case both the CT and MRI were negative). The accuracy of bone marrow oedema detection related to the acute injury is likely to have been affected by the long waiting period. Following this study, we aim to implement DECT on the day of the presentation to improve the accuracy of acute bone marrow oedema detection. Furthermore, our study included only 20 patients and given the sample size, the statistical power of this study is limited. However, it does offer insight into bone marrow oedema detection using the GE DECT scanner and its analysis platform.

The acquisition time for a scaphoid DECT is a few seconds compared to our MRI protocol, which takes around 15 min. Additionally, MRI is a more expensive test and often less readily available after hours in an emergency setting. Using DECT as the second-line investigation following a negative radiograph would result in significantly improved resource utilisation.

CT scans are also more acceptable to patients as they are less likely to induce claustrophobia and are less noisy. However, this has to be balanced with the increased radiation dose associated with CT compared to MRI.

**Conclusion**

DECT has the capacity to detect acute bone marrow oedema and identify subtle interruptions of scaphoid bony cortex to confirm a fracture. Its fast scanning time would be more suitable than MRI in the acute setting to exclude occult scaphoid fracture. A timely diagnosis would help avoid unnecessary treatments and follow-ups, as well as reduce the high reliance on MRI. However, further work is required on bone suppression algorithms to improve the sensitivity of subcortical bone marrow oedema detection.

**Supplementary Information** The online version contains supplementary material available at https://doi.org/10.1007/s00330-020-07604-z.

**Funding** The authors state that this work has not received any funding.

**Compliance with ethical standards**

**Guarantor** The scientific guarantor of this publication is Dr. Rajat Chowdhury.

**Conflict of interest** The authors of this manuscript declare no relationships with any companies whose products or services may be related to the subject matter of the article.

**Statistics and biometry** No complex statistical methods were necessary for this paper.

**Informed consent** Written informed consent was obtained from all subjects (patients) in this study.

**Ethical approval** Institutional Review Board approval was obtained.

**Methodology**

- prospective
- diagnostic or prognostic study
- performed at one institution

**Open Access** This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article’s Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article’s Creative Commons licence and your intended use is not

 Springer
References

1. Hove LM (1999) Epidemiology of scaphoid fractures in Bergen, Norway. Scand J Plast Reconstr Surg Hand Surg 33(4):423–426
2. Mallee W, Doornberg JN, Ring D, van Dijk CN, Maas M, Goslings JC (2011) Comparison of CT and MRI for diagnosis of suspected scaphoid fractures. J Bone Joint Surg Am 93(1):20–28
3. Groves AM, Kayani I, Syed R et al (2006) An international survey of hospital practice in the imaging of acute scaphoid trauma. AJR Am J Roentgenol 187(6):1453–1456
4. Guggenberger R, Gnann R, Hodler J et al (2012) Diagnostic performance of dual-energy CT for the detection of traumatic bone marrow lesions in the ankle: comparison with MR imaging. Radiology. 264(1):164–173
5. Wang CK, Tsai JM, Chuang MT, Wang MT, Huang KY, Lin RM (2013) Bone marrow edema in vertebral compression fractures: detection with dual-energy CT. Radiology. 269(2):525–533
6. Ai S, Qu M, Glazebrook KN et al (2014) Use of dual-energy CT and virtual non-calcium techniques to evaluate post-traumatic bone bruises in knees in the subacute setting. Skeletal Radiol 43(9):1289–1295
7. Reddy T, McLaughlin PD, Mallinson PI et al (2015) Detection of occult, undisplaced hip fractures with a dual-energy CT algorithm targeted to detection of bone marrow edema. Emerg Radiol 22(1):25–29
8. Booz C, Noske J, Albrecht MH et al (2019) Traumatic bone marrow edema of the calcaneus: evaluation of color-coded virtual non-calcium dual-energy CT in a multi-reader diagnostic accuracy study. Eur J Radiol 118:207–214
9. Dareez NM, Dahleslett KH, Engesland E, Lindland ES (2017) Scaphoid fracture: bone marrow edema detected with dual-energy CT virtual non-calcium images and confirmed with MRI. Skeletal Radiol 46:1753–1756
10. Ali IT, Wong WD, Liang T et al (2018) Clinical utility of dual-energy CT analysis of bone marrow edema in acute wrist fractures. AJR Am J Roentgenol 210(4):842–847
11. Mallee WH, Wang J, Poolman RW et al (2015) Computed tomography versus magnetic resonance imaging versus bone scintigraphy for clinically suspected scaphoid fractures in patients with negative plain radiographs. Cochrane Database Syst Rev 6:CD010023
12. Petriisch B, Kosmala A, Weng AM et al (2017) Vertebral compression fractures: third generation dual-energy CT for detection of bone marrow edema at visual and quantitative analyses. Radiology. 284:161–168
13. Kellock TT, Nicolaou S, Kim SY et al (2017) Detection of bone marrow edema in nondisplaced hip fractures: utility of a virtual unenhanced dual-energy CT application. Radiology. 284:798–922
14. Neuhaus V, Lennartz S, Abdullayev N et al (2018) Bone marrow edema in traumatic vertebral compression fractures: diagnostic accuracy of dual-layer detector CT using calcium suppressed images. Eur J Radiol 105:216–220
15. Biondi M, Vanzi E, De Otto G et al (2016) Water/cortical bone decomposition: a new approach in dual energy CT imaging for bone marrow oedema detection. A feasibility study. Phys Med 32(12):1712–1716

Publisher’s note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.