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A Comparison of Dual-Energy CT with MRI in the Detection of Traumatic Bone Marrow Edema in Distal Extremity Bones

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ABSTRACT

Objective: Our objective was to evaluate the performance of dual-energy computed tomography (DECT) in detecting post-traumatic bone marrow edema (BME) in distal extremities.

Materials and Methods: We prospectively studied 31 consecutive patients (25 males) who presented within the first four weeks following distal extremity traumas (wrist, n=19; ankle, n=14) (protocol number: 2017/74). All patients underwent DECT and magnetic resonance imaging (MRI) within three days of presentation. Two independent radiologists analyzed DECT images for fractures and BME qualitatively. Computed tomography (CT) numbers on Virtual non-calcium (VNCa) images were obtained in both edematous and non-edematous areas for quantitative consensus assessment. We used MRI as a reference standard.

Results: MRI identified BME in 56/71 bones (78.9%). The rates of BME detection on CT compared to MRI at the patient level were found to be statistically significantly lower, except for individuals over 40 years of age, women, those with 7–30 days between trauma and admission, and those with CT-detected fractures ($p<0.05$). The rates of BME detection on CT at the bone level, compared to MRI, were found to be statistically significantly lower ($p<0.01$), except for women and those with fractures detected on CT. The interobserver agreement for the qualitative analysis of BME was fair ($\kappa=0.407$ and $p<0.001$). DECT's diagnostic accuracy rates in predicting BME were significantly higher in patients with fractures ($p=0.028$). CT numbers in edematous areas were significantly higher than in non-edematous areas ($p<0.001$).

Conclusion: DECT may serve as an alternative for detecting post-traumatic BME in distal extremity bones. However, in our heterogeneous bone sample group, it exhibited low sensitivity and a low negative predictive value.

Keywords: Dual-energy computed tomography, trauma, bone marrow edema, distal extremity, MRI.

INTRODUCTION

The distal parts of the lower and upper extremities are among the most frequently injured areas in the body. Wrist and hand complaints accounted for 21.44% of all orthopedic emergency service admissions.[1] Bone marrow edema (BME), also known as a bone bruise or bone contusion, results from an increase in intracellular or extracellular fluid in the bone marrow, a closed compartment of the bone structure. This increased pressure in the bone marrow leads to movement and rest pain. Additionally, post-traumatic BME is a crucial radiological finding, as it is associated with various ligament and tendon injuries.[2,3] BME, characterized by an increased blood and fluid content in the bone marrow, can be detected using fluid-sensitive magnetic resonance imaging (MRI) sequences.[2,3]

While MRI is a widely accepted technique for evaluating BME, it is not routinely used in acute trauma settings due to its lengthy examination time and various patient-related contraindications. Dual-energy computed tomography (DECT) addresses these limitations and recognizes BME using material separation techniques.[4] Still, DECT's application is rarely used in multi-trauma patients. A recent meta-analysis indicates DECT's efficacy in detecting BME, boasting an overall specificity of 97% and sensitivity of 85%. DECT provides excellent diagnostic imaging for both the appendicular and spine skeleton (specificity of 98% and 93%, and sensitivity of 84% for both, respectively).[5] However, only one study involved the distal extremity in this meta-analysis. In that study, the diagnostic performance of BME primarily relied on patients diagnosed with fractures via radiography.[6] Several studies have assessed DECT's performance in diagnosing BME in distal extremities.[6–11] Yet, none evaluated the timing of patient hospital admissions post-trauma.

In this study, we aim to assess DECT's diagnostic performance in detecting post-traumatic BME in distal extremities during acute and subacute phases, using MRI as a reference standard.

MATERIAL AND METHODS

Study Population

This prospective, single-center study enrolled patients admitted to our hospital's emergency department and orthopedic outpatient clinic between January and February 2018. The study was approved by the Ethical Committee of İnönü University Faculty of Medicine (protocol number: 2017/74). All participants included in the study provided informed consent.

Inclusion criteria: Adult patients with suspected post-traumatic wrist or foot-ankle fractures who underwent computed tomography (CT) within the first four weeks post-trauma. Each participant first received a DECT scan, followed by an MRI scan.

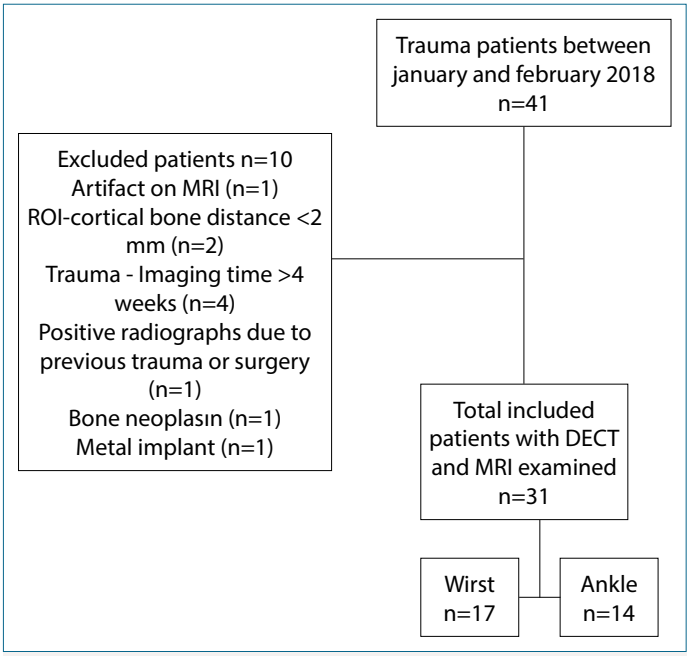

Figure 1. Flow chart of patients.

Exclusion criteria: Pediatric patients (under 18 years old), pregnant individuals, those with a history of surgery on the distal extremities, positive radiographs from previous traumas, bone neoplasm, and individuals with metal implants contraindicating MRI were excluded from the study.

After the exclusion of 10 out of the 41 referred patients, 31 were included in the study (Fig. 1).

Protocols of Imaging

All patients were scanned using a second-generation 128-segment dual-source CT scanner (Somatom, Siemens Healthcare). All MRI examinations were conducted on two 1.5 Tesla scanners (Avanto, Siemens Healthcare; Achieva, Philips) with a dedicated extremity coil. For this study, we employed a limited MRI protocol tailored to detect BME in trauma patients. The MRI examination consisted of coronal sequences for the wrist and sagittal sequences for the ankle (Table 1). In our study, the mean dose-length product was 218.16 mGy.cm ±49.9 (range: 97–303 mGy.cm). Literature indicates there is no significant difference in radiation exposure between conventional CT and DECT. However, the additional information, flexibility in post-imaging processing, and the absence of some routine imaging protocols in conventional CT make DECT advantageous in minimizing patient radiation exposure.[8]

Table 1. Protocols of imaging

	DECT protocol*			
Tube A voltage	80 kV	Tube B voltage	140 kV	
Tube A effective current	240 mAs	Tube B effective current	120 mAs	
Tin filter	0.6 mm	Section thickness	3 mm	
Collimation	32x0.6 mm	Pitch	0.7	
Rotation time	0.5	Dose reduction	CARE	

	MRI protocol							
	Wrist and hand				Ankle and foot			
	Siemens		Philips		Siemens		Philips	
	T1W_tse	T2W_fs	T1W_tse	T2W_fs	T1W_tse	T2W_fs	T1W_tse	T2W_fs
TR (ms)	561	4190	710	3170	710	3170	500	4491
TE (ms)	12	49	22	60	22	60	20	60
ST (mm)	3	3	3	3	3	3	3	3
AM	253x320	205x256	256×320	240x320	256×320	240x320	428x270	228x167
FOV (mm)	130	130	160	160	160	160	180	180
Bandwidth (Hz/Px)	174	181	166	161	166		292	134

*: 128-section dual-energy CT scanner (Siemens); TR: Repetition time; TE: Echo time; FOV: Field of view; AM: Acquisition matrix; ST: Section thickness; T1W_tse: T1-Weighted turbo spin-echo sequence; T2W_fs: T2-Weighted fat-saturated sequence.

DECT Post-Processing

DECT images were transferred to a post-processing workstation (Syngo. Via VB20A-HF01, Siemens Healthcare). Axial images were reconstructed for both a soft tissue kernel and a bone kernel (80-kVp set, 140-kVP set, and an average-weighted set). Images were further reconstructed in three planes with a section thickness of 0.75 mm and an increment of 0.5 mm (B60f). Virtual non-calcium images (VNCa) were derived from the images separated into three components. The data were color-coded to correlate the increased density between normal bone marrow areas and edematous regions. Both 3D volume rendering maps and triplane reconstructed VNCa images were color-coded (BME: green; normal bone marrow: blue).

Image Evaluation

DECT and MRI images were subjected to both qualitative and quantitative analysis. Initially, two independent radiologists analyzed all DECT images, being blinded to each other's assessments and MRI findings: reader 1 (R1) with four years of general radiology experience and one year in musculoskeletal (MSK) imaging, and reader 2 (R2) with 15 years in general radiology and six years in MSK imaging. All radiologists remained unaware of the patients' clinical data. Each bone was evaluated for the presence of BME on multiplanar reformat VNCa images utilizing a three-point classification system: 1 for edema present, 2 for edema suspected, and 3 for no edema. Additionally, any fractures were noted on the multiplanar grayscale VNCa CT images. In a subsequent reading session, another radiologist (reader 3 (R3) with 12 years of general radiology experience) assessed the presence of BME on MRI (0=no BME, 1=BME present), uninformed of the clinical and DECT data. BME is best visualized on a fat-suppressed T2W MRI sequence. An intermediate or low T1W signal paired with a high T2 signal in the bone marrow is classified as BME. In a third reading session (one month after the initial visual assessment), R1 and R2 collaboratively reviewed the images to settle any disagreements on bone fractures or BME presence (Fig. 2). Subsequently, for the quantitative analysis, DECT images were compared to MRI results by R1 and R2 to reach a consensus. Hounsfield Unit (HU) numbers were measured at both edematous and non-edematous sites, or adjacent healthy bones on the DECT maps using a circular region of interest (ROI). ROIs with cross-sectional areas between 0.1–0.4 cm^2 were placed at least 2 mm from the cortical bone center to prevent artifacts (Fig. 3).

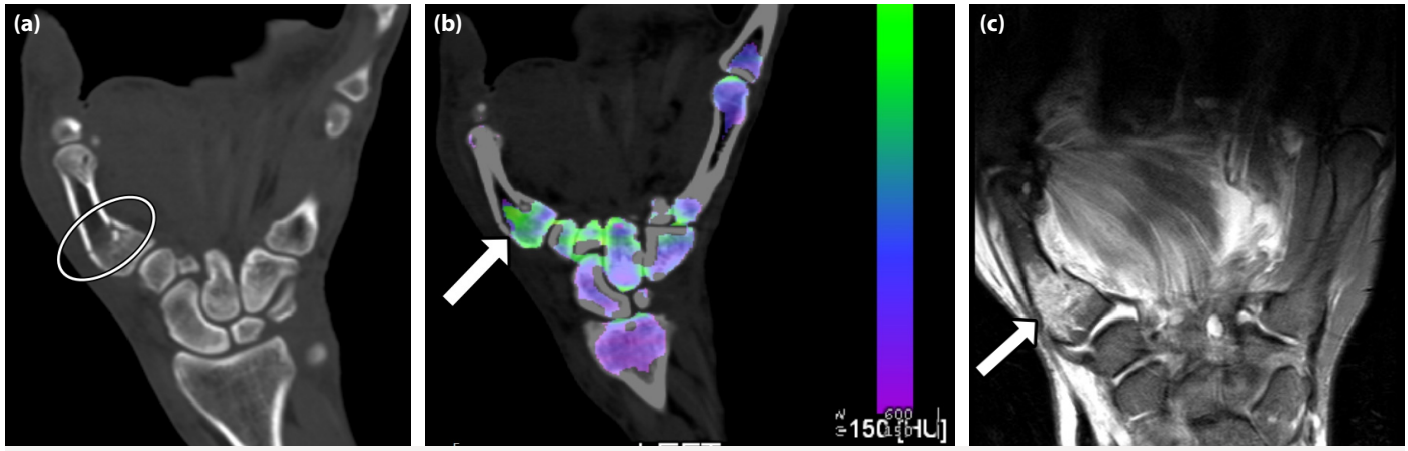

Figure 2. Images in a 57-year-old man with clinical suspicion of a wrist fracture one day after trauma: **(a)** Coronal reformation of a conventional CT reconstruction, **(b)** Dual-energy CT color-coded virtual noncalcium, and **(c)** Coronal fat-saturated T2-weighted MRI scan image of the right wrist. Bone marrow edema is visible both in the MRI and dual-energy CT (arrow in **b** and **(c)** at the first metacarpal base. Extraarticular fracture lines are evident in the conventional CT image (ellipse in **a**).

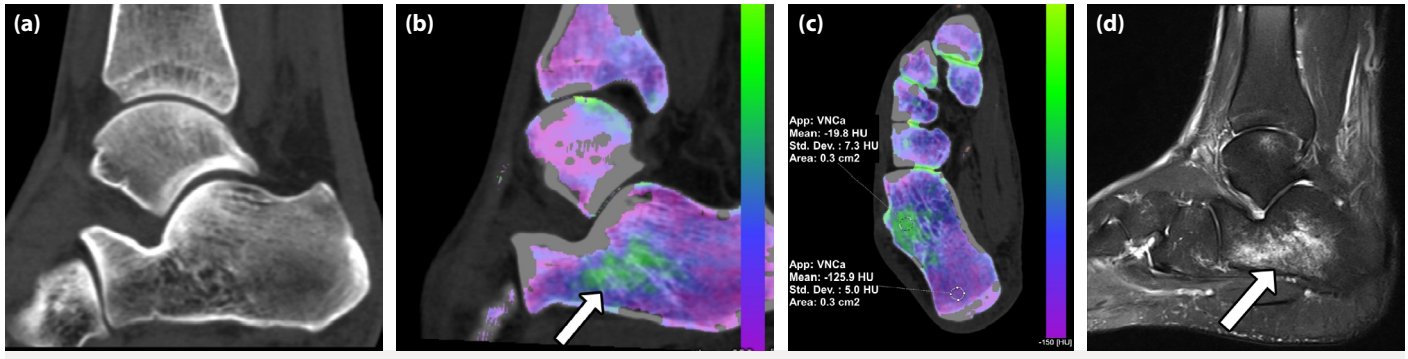

Figure 3. Images in a 34-year-old man with clinical suspicion of an ankle fracture 14 days after trauma: **(a)** Sagittal reformation of a conventional CT reconstruction, **(b, c)** DECT color-coded virtual noncalcium, and **(d)** Sagittal fat-saturated T2-weighted MRI scan image of the right ankle. Bone marrow edema in the calcaneus without fracture is visible both in the MRI and dual-energy CT (arrow in B and D). A significant difference in CT numbers between the areas with and without edema can be seen (circles in C) on the color-coded DECT image. Also, note the bone marrow edema of the talar dome (arrow in D) visible on MRI, which is not as pronounced in the color-coded DECT image.

Statistical Analysis

Statistical analyses were executed using the IBM Statistical Package for the Social Sciences (SPSS) Statistics version 25.0 software (IBM Corporation, Armonk, NY, USA). The Shapiro-Wilk test assessed normal distribution. Kappa coefficients were calculated to define the inter-observer agreement levels for DECT evaluations. All statistical analyses evaluating the diagnostic success of DECT were reached through consensus. The efficacy of DECT assessments in predicting BME relative to MRI was determined by calculating diagnostic performance indicators. The McNemar test was applied to gauge the diagnostic performance of DECT in estimating BME on both the bone and patient levels. The differences in HU levels between areas with and without BME according to DECT were evaluated using the Mann-Whitney U test. For the receiver operating characteristics (ROC) analysis, Hounsfield Unit numbers on the DECT maps and MRI (the reference test) were considered. This ROC analysis determined the optimal cutoff point for HU measurements to detect BME. A p-value<0.05 was considered statistically significant.

RESULTS

A total of 31 patients, with a mean age of 36.7 years ±15.5 (range: 19–70 years), were included in the study. Out of these, 25 (80.6%) were males with a mean age of 37.8 years ±14.4.

Table 2. Demographic and clinical characteristics of the study population (n=31)

	n	%
Age (years)	36.7±15.5	
Age range (years)	19–70	
Age groups		
<40 age	18	58.1
≥40 age	13	41.9
Gender		
Male	25	80.6
Female	6	19.4
Region		
Ankle	14	42.42
Wrist	19	57.58
Time between trauma and CT scan		
0–6 days	18	58.1
7–30 days	13	41.9
Time between CT and MRI		
<24 hours	27	87.2
1 day	2	6.4
2 days	2	6.4

CT: Computed tomography; MRI: Magnetic resonance imaging.

The study examined 71 bones across 33 joint regions, specifically the wrist (n=19) and ankle (n=14). Two of the patients reported a history of trauma to both wrists. On average, the interval between DECT and MRI was 0.29 days (range: 0–3 days). Among all participant, 18 (58.1%) were admitted to the hospital in an acute setting (median: 0 days; range: 0–3 days), and 13 (41.9%) in a subacute setting (median: 7 days; range: 7–30 days). CT scans for all patients were taken on their admission day. Fractures and BME on multiplanar VNCa images were recorded in 11/31 (35.5%) and 12/31 (38.71%) patients, respectively (Table 2).

We identified fractures with BME in seven bones (two radiuses, one trapezoid, one pisiform, one first metacarpal, one lateral malleolus, and one cuboid). In contrast, fractures without BME were observed in four bones (one fourth middle phalanx, one third metatarsal, one medial cuneiform, and one tibial plafond). Additionally, BME without fractures was present in eight bones (two metacarpals, one capitate, one radius, one talus, two calcanei, and one medial cuneiform) as seen on DECT images.

MRI results indicated BME in 23/31 (74.2%) patients and 56/71 (78.9%) bones. However, DECT detected BME in only 12/31 (38.71%) patients and 15/56 (26.8%) bones that showed edema on MRI. BME detection rates at the patient level on DECT were statistically significantly lower than MRI for individuals under 40 years, males, those with a 0–6 day interval post-trauma, and those without CT-detected fractures (p=0.016; p=0.004; p=0.016; p=0.008, respectively) (Table 3). Although DECT's clinical performance might seem inadequate, it is a statistically significant predictor for BME detection at both the patient and bone levels (p=0.012 and p=0.030, respectively). At the patient level, the sensitivity stood at 52.2% and specificity at 100% (Table 4). Comparisons between MRI and DECT at the bone level revealed that BME detection rates on CT were consistently statistically significantly lower than MRI, with exceptions for female patients and individuals with CT-detected fractures (p<0.01) (Table 5). Bone-level sensitivity was 26.8%, and specificity was 100% (Table 6). For BME qualitative analysis on DECT images, the overall interobserver agreement was found to be fair (κ=0.407 with p<0.001).

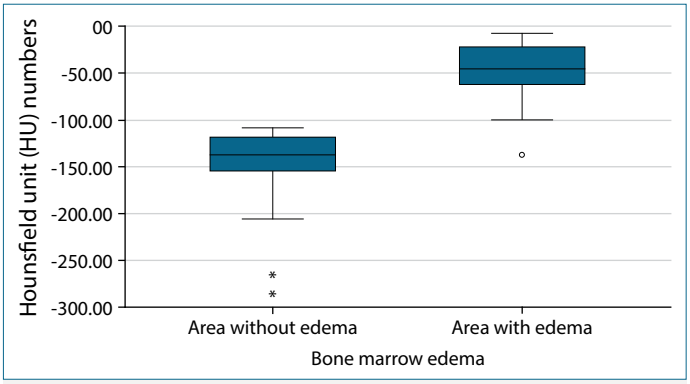

Figure 4. Comparison of bone marrow areas with and without edema. The horizontal lines in the middle of each box represent the median, while the top and bottom borders of the box denote the 25th and 75th percentiles, respectively. The whiskers above and below the box indicate the maximum and minimum HU levels. The open circle and asterisks represent outlier cases. Areas with edema: -45.20 (IQR; -62.35 – -22.62); Areas without edema: -137.10 (IQR; -155.85 – -118.87) (p<0.001).

There was a statistically significant difference in CT values between regions with and without edema: -45.20 (IQR: -62.35 to -22.62) vs. -137.10 (IQR: -155.85 to -118.87) (p<0.001) (Fig. 4). Moreover, CT values in edematous areas were statistically significantly higher in patients with fractures than those without (p=0.046). The ROC analysis revealed an Area Under the Curve (AUC) of 0.975 (95% CI: 0.925–1.000 with p<0.001). Utilizing a cut-off value of -104 HU for BME identification yielded a sensitivity of 95.0% and specificity of 100%.

Table 3. Comparisons between MRI and DECT in terms of BME within several subgroups (patient level)

DECT	MRI						p†
	Normal		BME		Total		
	n	%	n	%	n	%	
<40 age							**0.016**
Normal	3	16.7	7	38.9	10	55.6	
BME	0	0.0	8	44.4	8	44.4	
Total	3	16.7	15	83.3	18	100.0	
≥40 age							0.125
Normal	5	38.4	4	30.8	9	69.2	
BME	0	0.0	4	30.8	4	30.8	
Total	5	38.4	8	61.6	13	100.0	
Male							**0.004**
Normal	7	28.0	9	36.0	16	64.0	
BME	0	0.0	9	36.0	9	36.0	
Total	7	28.0	18	72.0	25	100.0	
Female							0.5
Normal	1	16.7	2	33.3	3	50.0	
BME	0	0.0	3	50.0	3	50.0	
Total	1	16.7	5	83.3	6	100.0	
0–6 days between trauma and CT scan							**0.016**
Normal	5	27.8	7	38.9	12	66.7	
BME	0	0.0	6	33.3	6	33.3	
Total	5	27.8	13	72.2	18	100.0	
7–30 days between trauma and CT scan							0.125
Normal	3	23.1	4	30.8	7	53.9	
BME	0	0.0	6	46.1	6	46.1	
Total	3	23.1	10	76.9	13	100.0	
No fracture on CT							**0.008**
Normal	8	40.0	8	40.0	16	80.0	
BME	0	0.0	4	20.0	4	20.0	
Total	8	40.0	12	60.0	20	100.0	
Fracture on CT							N/A
Normal	0	0.0	3	27.3	3	27.3	
BME	0	0.0	8	72.7	8	72.7	
Total	0	0.0	11	100.0	11	100.0	
General							<**0.001**
Normal	8	25.8	11	35.5	19	61.3	
BME	0	0.0	12	38.7	12	38.7	
Total	8	25.8	23	74.2	31	100.0	

All prevalences were calculated with respect to the total number of cases. †: McNemar Test; N/A: Not applicable; BME: Bone marrow edema; CT: Computed tomography; MRI: Magnetic resonance imaging; DECT: Dual-energy computed tomography.

Table 4. Diagnostic performance of dect in predicting BME: Patient level

	Number of cases (n)	Sensitivity (%)	Specificity (%)	PPV (%)	NPV (%)	Accuracy (%)
Age groups						
<40 age	18	53.3 (8/15)	100 (3/3)	100 (8/8)	30 (3/10)	61.1 (11/18)
≥40 age	13	50 (4/8)	100 (5/5)	100 (4/4)	55.6(5/9)	69.3(9/13)
Gender						
Male	25	50 (9/18)	100 (7/7)	100 (9/9)	43.8 (7/16)	64 (16/25)
Female	6	60 (3/5)	100 (1/1)	100 (3/3)	33.3 (1/3)	66.7 (4/6)
Time between trauma and CT scan						
0–6 days	18	46.2 (6/13)	100 (5/5)	100 (6/6)	41.7 (5/12)	61.1 (11/18)
7–30 days	13	60 (6/10)	100 (3/3)	100 (6/6)	42.9 (3/7)	69.3 (9/13)
Fracture on CT						
Absent	20	33.3 (4/12)	100 (8/8)	100 (4/4)	50 (8/16)	60 (12/20)
Present	11	72.7 (8/11)	N/A	100 (8/8)	N/A	72.7 (8/11)
General	31	52.2 (12/23)	100 (8/8)	100 (12/12)	42.1 (8/19)	64.5 (20/31)

n: Total number of cases; BME: Bone marrow edema; CT: Computed tomography; PPV: Positive predictive value; NPV: Negative predictive value; N/A: Not applicable.

There was no statistically significant difference in DECT's ability to predict BME based on age groups, gender, or the time interval between trauma and DECT (p>0.05). However, the diagnostic accuracy of DECT in predicting BME was statistically higher in patients with fractures compared to those without fractures (p=0.028).

DISCUSSION

In this study, using a DECT scanner with a virtual non-calcium (VNCa) technique, we demonstrated that DECT can detect bone marrow edema (BME) in patients with distal extremity trauma with impressive specificity and positive predictive value. Furthermore, we discovered no statistically significant difference in predicting BME with DECT based on the time interval between trauma and the CT scan within the first month. Although our findings advocate that DECT can serve as a valuable screening tool, its high false-negative rate renders it suboptimal for diagnosing traumatic BME of distal extremity bones.

Recently, several meta-analysis articles have been published on the diagnostic performance of DECT.[5–7] These articles suggest that DECT possesses high diagnostic accuracy in detecting BME in both the spine and the appendicular skeleton. In the latest meta-analysis, Wilson et al.[8] posited that DECT could serve as an alternative to MRI for BME detection. The authors of this study found that DECT has a higher specificity (93%) than sensitivity (86%) for the appendicular skeleton.[8] Furthermore, they noted that quantitative analysis has a higher sensitivity (p=0.01) and similar specificity (p=0.28) when compared to qualitative analysis, based on meta-regression.[8] It is essential to remember that certain patient- or study-related variables, such as age, bone size, reader experience variations, and reference standards, were not evaluated in this study.[8]

Several studies have delved into the diagnostic utility of DECT concerning wrist[9–13] and ankle injuries.[14–16] Using MRI as a reference standard, the sensitivity and specificity of DECT ranged between 90%–94% and 80.5%–98% respectively for detecting traumatic BME in certain studies.[12,14,16] In another prospective study focusing on wrist trauma, Müller et al.[10] demonstrated that DECT exhibited moderate sensitivity (69% at the bone level) and high specificity (98% at the bone level) for detecting traumatic BME of the wrist. In our current study, we found the sensitivity and specificity of DECT to be 52.2% and 100% at the patient level, and 26.8% and 100% at the bone level respectively, for depicting traumatic BME of the upper and lower distal extremities. Our findings display lower sensitivity rates compared to other similar studies.[10,12,14,16] Unique to our research, we also examined the bones of the hand and foot, which other studies did not. The decreased sensitivity of DECT in our research, in comparison to its specificity, might be attributed to our study population that included bones of varying sizes and shapes, differing levels of reader experience, or variations in scanner settings and post-processing parameters. Two additional studies have discussed DECT's ability to detect BME in inflammatory arthritis of the hand and foot in the literature, but neither mentioned sensitivity and specifici-

Table 5. The comparisons between MRI and DECT in terms of BME within several subgroups (bone level)

DECT	MRI						p†
	Normal		BME		Total		
	n	%	n	%	n	%	
<40 age							<**0.001**
Normal	8	15.7	32	62.7	40	78.4	
BME	0	0.0	11	21.6	11	21.6	
Total	8	15.7	43	84.3	51	100.0	
≥40 age							**0.004**
Normal	7	35.0	9	45.0	16	80.0	
BME	0	0.0	4	20.0	4	20.0	
Total	7	35.0	13	65.0	20	100.0	
Male							<**0.001**
Normal	14	22.6	36	58.0	50	80.6	
BME	0	0.0	12	19.4	12	19.4	
Total	14	22.6	48	77.4	62	100.0	
Female							0.063
Normal	1	11.1	5	55.6	6	66.7	
BME	0	0.0	3	33.3	3	33.3	
Total	1	11.1	8	88.9	9	100.0	
0–6 days between trauma and CT scan							<**0.001**
Normal	12	27.3	25	56.8	37	84.1	
BME	0	0.0	7	15.9	7	15.9	
Total	12	27.3	32	72.7	44	100.0	
7–30 days between trauma and CT scan							<**0.001**
Normal	3	11.1	16	59.3	19	70.4	
BME	0	0.0	8	29.6	8	29.6	
Total	3	11.1	24	88.9	27	100.0	
No fracture on CT							<**0.001**
Normal	14	23.7	38	64.4	52	88.1	
BME	0	0.0	7	11.9	7	11.9	
Total	14	23.7	45	76.3	59	100.0	
Fracture on CT							0.25
Normal	1	8.3	3	25.0	4	33.3	
BME	0	0.0	8	66.7	8	66.7	
Total	1	8.3	11	91.7	12	100.0	
General							<**0.001**
Normal	15	21.1	41	57.8	56	78.9	
BME	0	0.0	15	21.1	15	21.1	
Total	15	21.1	56	78.9	71	100.0	

All prevalences were calculated regarding the total number of cases. †: McNemar Test; BME: Bone marrow edema; CT: Computed tomography; MRI: Magnetic resonance imaging; DECT: Dual-energy computed tomography.

Table 6. Diagnostic performance of DECT in predicting BME: Bone level

	Number of cases (n)	Sensitivity (%)	Specificity (%)	PPV (%)	NPV (%)	Accuracy (%)
Age groups						
<40 age	51	25.6 (11/43)	100 (8/8)	100 (11/11)	20 (8/40)	37.3 (19/51)
≥40 age	20	30.8 (4/13)	100 (7/7)	100 (4/4)	43.8 (7/16)	55 (11/20)
Gender						
Male	62	25 (12/48)	100 (14/14)	100 (12/12)	28 (14/50)	42 (26/62)
Female	9	37.5 (3/8)	100 (1/1)	100 (3/3)	16.7 (1/6)	44.4 (4/9)
Time between trauma and CT scan						
0–6 days	44	21.9 (7/32)	100 (12/12)	100 (7/7)	32.4 (12/37)	43.2 (19/44)
7–30 days	27	33.3 (8/24)	100 (3/3)	100 (8/8)	15.8 (3/19)	40.7 (11/27)
Fracture on CT						
Absent	59	15.6 (7/45)	100 (14/14)	100 (7/7)	26.9 (14/52)	35.6 (21/59)
Present	12	72.7 (8/11)	100 (1/1)	100 (8/8)	25 (1/4)	75 (9/12)
General	71	26.8 (15/56)	100 (15/15)	100 (15/15)	26.8 (15/56)	42.2 (30/71)

n: Total number of cases; BME: Bone marrow edema; CT: Computed tomography; PPV: Positive predictive value; NPV: Negative predictive value; N/A: Not applicable.

ty values.[17,18] Consequently, despite recent studies, the ability of DECT to detect BME in hand and foot trauma remains undetermined. In their study on DECT for suspected radiographically negative wrist fractures, the authors demonstrated that DECT had high sensitivity (85%) in detecting bones with fractures, but only moderate sensitivity (69%) in detecting bones with BME.[10] Consistent with these findings, our results also indicated that the diagnostic accuracy rates of DECT in predicting BME were statistically higher in patients with fractures than in those without.

We measured the CT number of bone marrow on VNCa maps and observed a significant difference between edematous and non-edematous areas, consistent with previous studies.[9,12,14–16] Furthermore, the CT numbers for fractures with BME were higher than those without fractures. Notably, we calculated a cut-off value of -104 HU for diagnosing BME, which diverges from other studies focusing on the ankle and wrist regions,[9,12,14–16] where the optimal cut-off values ranged from +5.90 to -80 HU.[9,12,14–16] Guggenberger et al.[14] achieved moderate sensitivity and good specificity using different cut-off values for various anatomical areas: -80 HU for ankle mortise, -70 HU for the talar dome, and -39 HU for the talar trunk/head. The discrepancy in the relative cut-off values compared to previous studies might be attributed to the use of different generation scanners (second or third-generation) or different parameters (ranging from 80–140 kV, 80–150 kV to 90–140 kV).[10,13,15–17] Another possible explanation lies in the different methods chosen for ROI placement. Like Guggenberger et al.,[14] we positioned the ROIs at the location with the highest signal intensity on MRI. However, other researchers opted to place ROIs at locations with the highest density changes on DECT maps.[15] Additionally, our study included smaller bones of the foot and hand (such as the phalanges), which were excluded in other studies. CT numbers may differ from the carpal and tarsal bones to the phalanges. Factors like patient age or concurrent conditions – like anemia or smoking – that can influence the ratio between red and yellow bone marrow, may also cause notable variations in CT values. One meta-analysis highlighted that quantitative analysis demonstrated higher sensitivity than qualitative analysis. While several studies have shown that quantitative analyses offer excellent diagnostic accuracy, our experience suggests that quantitative analysis may not be ideal for routine workflows. This hesitancy is due to the additional time required for measurement and the inconsistency of cut-off values across studies.[12,16]

In the literature, several studies have discussed the time interval between trauma and DECT. It has been reported that the duration for bone bruise resolution can range broadly, from three weeks to two years.[19–22] Ai et al.[19] evaluated traumatic BME of knees in the subacute setting on DECT retrospectively, while Björkman et al.[20] did so prospectively (with median time intervals between trauma and DECT of 37 days and 25 days, respectively). Ai et al.[19] emphasized that DECT can detect post-traumatic BME for at least ten weeks. Björkman et al.[20] indicated that there was no statistical difference in the time interval from trauma to DECT among the groups of true positives

and negatives, and false positives and negatives. Additionally, DECT demonstrated a significantly lower sensitivity in diagnosing BME during the hyperacute stage (<24 hours) compared to the acute stage (≥24 hours).[6] In our study, the diagnostic accuracy of DECT conducted within 30 days post-trauma was statistically significantly lower compared to MRI at the bone level. Furthermore, the diagnostic success of DECT (bone level) based on the presence of a fracture was statistically significantly lower in those without fractures, whereas it was higher – but not statistically significant – in those with fractures.

To the best of our knowledge, our study is the first study to investigate traumatic BME on DECT in either an acute or subacute setting. We found no statistically significant difference in the DECT's predictive capability for BME based on the time interval between the trauma and the DECT scan, whether in the acute setting (median, 0 days; range, 0–3 days) or the subacute setting (median, 7 days; range, 7–30 days). While DECT is not available in every healthcare facility, it may serve as an alternative imaging modality for patients contraindicated for MRI due to BME or bone fractures, which are prevalent conditions.

Our study has several limitations. Firstly, the sample size was small, necessitating future studies with larger sample sizes. Secondly, the study population was not homogeneous, encompassing both upper and lower extremities. Given the differences in bone sizes, BME is naturally easier to detect in larger bones. Thirdly, our inclusion of only patients referred during weekday working hours may have introduced potential bias in the types of injuries. Fourthly, the relatively young age of our study group suggests that different scanner settings and post-processing parameters may be required to detect BME in older age groups due to changes in bone density. Lastly, we did not make comparisons between qualitative and quantitative analyses. Although several studies have indicated that quantitative analyses possess excellent diagnostic accuracy, we believe that they may not be suitable for routine workflow due to the additional time they require and the variability in cut-off values among different studies.

CONCLUSION

In conclusion, DECT may serve as an alternative for detecting traumatic BME in distal extremity bones. However, it has a lower sensitivity and negative predictive value compared to MRI.

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