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Research Article

ROLE OF DUAL-ENERGY COMPUTED TOMOGRAPHY IN THE EMERGENCY DIAGNOSIS OF KNEE BONE MARROW EDEMA: A COMPARATIVE STUDY WITH MAGNETIC RESONANCE IMAGING

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ABSTRACT

Objective: Key markers of injury processes in acute knee trauma are bone bruises, which are detected by magnetic resonance imaging (MRI) as increased signal intensity on T2-weighted images and signal loss on T1-weighted imaging. However, due to its restricted availability and lengthy acquisition times, particularly in emergency situations, MRI is not often employed in knee trauma cases. A viable substitute is dual-energy computed tomography (DECT) with virtual non-calcium (VNCa) techniques, which improves bone marrow edema (BME) visibility and allows for greater material distinction. This study uses MRI as the reference standard to assess the diagnostic performance of third-generation DECT and VNCa methods for detecting BME in acute knee injuries.

Methods: This prospective observational study involved 40 patients with acute knee trauma who had both MRI and DECT between July 2019 and July 2021 at Kovai Medical Center and Hospital in Coimbatore. Individuals who were pregnant had a history of knee injuries or were above the age of 18 were eliminated, as were those who had an MRI or CT contraindication. Siemens Healthcare's Somatom Force, a third-generation 192-slice dual-source CT scanner, was used for DECT imaging, while Philips Ingenia 1.5T was used for MRI. Image analysis used SPSS version 27.0 for statistical analysis to determine whether BME was present in MRI and DECT images.

Results: The study participants had a mean age of 47±16 years, predominantly male (72.5%). DECT demonstrated a sensitivity of 81.15% and a specificity of 96.70% for detecting BME compared to MRI. The diagnostic accuracy was notably high in the lateral femoral condyle (sensitivity and specificity of 93.33%) and the lateral tibial condyle (sensitivity and specificity of 86.36%). Overall, DECT identified 59 out of 69 MRI-positive regions, reflecting its robustness in detecting true positives and true negatives in acute trauma settings.

Conclusion: Third-generation DECT with VNCa techniques is a highly effective imaging modality for detecting edema of the bone marrow in acute knee trauma, offering high diagnostic accuracy comparable to MRI. It is ability to provide clear visual differentiation and rapid acquisition makes it a valuable alternative, particularly in emergency settings where MRI is unavailable or contraindicated. DECT's shorter reconstruction time and high reliability can optimize workflow and improve patient outcomes, underscoring its potential role in early diagnosis and management of knee trauma.

Keywords: Dual-energy computed tomography, Virtual non-calcium, Bone marrow edema, Acute knee trauma, Magnetic resonance imaging.

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INTRODUCTION

A poorly-marginated area of signal loss on T1-weighted images (T1WIs) involving the subcortical bone combined with elevated signal intensity on T2-weighted images is indicative of a bone bruise. This appearance typically represents hemorrhage, edema, or infarction resulting from trabecular microfracture [1]. Despite its frequent identification through magnetic resonance imaging (MRI) following musculoskeletal injuries, MRI is not routinely performed for all knee trauma cases due to its long acquisition times and varying availability, particularly in emergency settings [2].

Bone bruises can cause significant pain even in the absence of substantial soft-tissue injuries and may lead to persistent marrow edema, subchondral osteonecrosis, or articular cartilage degeneration if not diagnosed early and managed appropriately [3]. Conventional computed tomography (CT), while advantageous for its rapid acquisition times and fine bone detail, lacks the sensitivity of MRI for detecting bone marrow edema (BME). This limitation arises from its inability to adequately remove fine trabecular bone, resulting in suboptimal visualization of the bone marrow cavity [4].

Dual-energy CT (DECT) offers a promising alternative by leveraging superior material differentiation through the virtual non-calcium (VNCa) technique, which effectively subtracts the highly attenuating calcium signal of bone. This allows for enhanced imaging evaluation of bone marrow, making DECT a valuable tool in the emergency room trauma setting [5]. The VNCa technique facilitates the detection of BME, presenting it in various imaging formats such as color imaging, gray-scale overlay, or 3D according to the reader's preference [5].

Hence this study was planned with the objectives to estimate the diagnostic accuracy of DECT, using MRI as the standard of reference in assessing BME. This study is necessary to validate DECT as a reliable alternative to MRI for rapid and accurate detection of BME in emergency settings, thereby improving patient outcomes through timely diagnosis and intervention.

METHODS

This study was carried out in the Radiology Department of Radiology at a tertiary care setup. The Institute Ethical and scientific committee approved the trial, which included 40 adult patients over the age of 18

who had MRI and DECT for acute knee trauma between July 2019 and July 2021. All participants provided written informed consent. This prospective observational study evaluated the diagnostic performance of third-generation DECT and VNCa techniques for detecting BME, with MRI serving as gold standard. To guarantee acceptable statistical power, a sample size of 40 patients was chosen using prior investigations.

Patients included were over 18 years old with a history of acute knee trauma who had undergone both MRI and DECT, showing bone contusions on MRI. Exclusion criteria included contraindications to MRI or CT, patients under 18 years, and pregnant patients. MRI of the knee was performed using a Philips Ingenia 1.5T system with a surface coil, including PD, T1-weighted, T2-weighted, and short tau inversion recovery (STIR) images in sagittal orientation. Bone contusions were identified by increased signal intensity on STIR and decreased signal intensity on T1WIs.

DECT imaging was conducted using a third-generation 192-slice dual-source CT scanner (Somatom Force; Siemens Healthcare). The scanner utilized two x-ray tubes and detectors with an angle of 90°. Imaging was performed with a dual-energy protocol, including automated attenuation-based tube current modulation. Post-processing involved using a dual-energy iterative reconstruction kernel and commercially available software to create VNCa images. These images were displayed as color-coded maps for further analysis, with BME identified by specific color coding.

Image analysis was conducted with each knee joint evaluated for BME. The presence of BME was determined by the appearance of specific color codes on DECT images. Statistical analysis of the data, including sensitivity, specificity, accuracy, positive predictive value (PPV), and negative predictive value (NPV), was performed using SPSS version 27.0 software.

RESULTS

The study population comprised 40 patients who underwent DECT and MRI in an acute knee trauma setting, with a mean age of 47±16 years. The majority of the patients were aged between 31 and 40 years (25%). Gender distribution indicated a predominance of males (72.5%) over females (27.5%). The interval between injury and DECT/MRI had a mean of 4.2 days, with a median of 4.0 days, and a range of 1–7 days. The distribution of bone bruises in MRI revealed that the highest frequency was in patients with one region affected (47.5%), followed by two regions (35%). For DECT, the highest frequency was also in patients with one region affected (60%), followed by two regions (27.5%) (Table 1).

The detailed comparison of contusions detected in different knee regions using MRI and DECT reveals varying degrees of diagnostic accuracy. In the medial femoral condyle, DECT demonstrated a sensitivity and specificity of 71.43%, identifying 10 true positives out of 14 MRI-detected contusions. The lateral femoral condyle showed higher accuracy, with DECT achieving a sensitivity and specificity of 93.33%, detecting 14 true positives out of 15. For the medial tibial condyle, DECT had a sensitivity and specificity of 72.22%, identifying 13 true positives out of 18. The lateral tibial condyle exhibited a sensitivity and specificity of 86.36%, with DECT correctly identifying 19 true positives out of 22. Overall, DECT displayed high sensitivity and specificity in the lateral femoral condyle and lateral tibial condyle, indicating its reliability in these regions, while performance was moderate in the medial femoral and medial tibial condyles (Table 2).

The diagnostic performance of DECT maps over MRI in diagnostic contusions was evaluated. The true positive rate was 56, and the true negative rate was 88. There were 3 false positives and 13 false negatives. The sensitivity of DECT was calculated at 81.15%, indicating its capability to detect true positives effectively. The specificity was 96.70%, reflecting a high accuracy in identifying true negatives. The PPV was 94.91%, and the NPV was 87.12%. The overall accuracy of DECT maps stood at 90%, with a positive likelihood ratio (LR) of 24.61 and a negative LR of 0.19, showcasing its high diagnostic reliability and effectiveness in the qualitative assessment of knee contusions (Table 3).

Table 1: Distribution of study population according to sociodemographic parameters

Sociodemographic parameter	Category	Frequency	Percent
Age distribution	21–30 years	7	17.5
	31–40 years	10	25
	41–50 years	5	12.5
	51–60 years	7	17.5
	61–70 years	9	22.5
	Above 70 years	2	5
	Mean±S.D =47±16 years		
Gender distribution	Female	11	27.5
	Male	29	72.5
	Total	40	100
Interval between injury and MRI/ DECT	Mean	-	4.2 days
	Median	-	4.0 days
	SD	-	1.9
	Range	-	6
	Minimum	-	1
	Maximum	-	7
No. of regions with bone bruise in MRI	I	19	47.5
	II	14	35
	III	6	15
	IV	1	2.5
No. of regions with bone bruise in DECT	Zero	1	2.5
	I	24	60
	II	11	27.5
	III	3	7.5
	IV	1	2.5

MRI: Magnetic resonance imaging, DECT: Dual-energy computed tomography, SD: Standard deviation

DISCUSSION

In this prospective investigation, we employed a third-generation DECT scanner with a VNCa approach to detect BME in acute knee injuries, using MRI as gold standard. Our study included 40 patients. The majority of respondents were male (72.5%), with the most prevalent age categories being 31–40 years (25%), and 61–70 years (22%). These patients had recent trauma, with imaging performed within 1 to 7 days post-injury. Bone bruises are significant indicators of injury mechanisms and can provide insights into associated soft-tissue injuries, making their evaluation clinically important [6,7].

The DECT approach in this study effectively subtracted calcium from cancellous bone, revealing minor attenuation changes associated with fractures, known as BME. VNCa pictures were analyzed using a three-material breakdown technique, revealing distinct bone mineral, yellow marrow, and red marrow. These images were displayed as color-coded maps, facilitating visual or qualitative analysis [8,9].

Previous studies have shown high sensitivities (86–90%) and NPVs (95–99%) of DECT relative to MRI for detecting bone bruising in knee and ankle trauma [10]. Our study found a comparable sensitivity of 81.15% and a higher specificity of 96.70%, indicating robust diagnostic performance. Pache *et al*. first reported the use of DECT for detecting post-traumatic bone marrow lesions in the knee, demonstrating high sensitivities and specificities using a first-generation DECT scanner [11]. Our results align with these findings, showcasing similar sensitivity and higher specificity.

Björkman *et al*., assessed the diagnostic accuracy of DECT for bone marrow lesions in subacute knee injuries, reporting moderate sensitivity

Table 2: Contusions distribution in different regions

Region	Total contusions in MRI	Total contusions in DECT	False positive contusions	False negative contusions	True positives	True negatives	Sensitivity (%)	Specificity (%)
Medial femoral condyle	14	11	1	4	10	4	71.43	71.43
Lateral femoral condyle	15	16	2	1	14	1	93.33	93.33
Medial tibial condyle	18	13	0	5	13	5	72.22	72.22
Lateral tibial condyle	22	19	0	3	19	3	86.36	86.36

MRI: Magnetic resonance imaging, DECT: Dual-energy computed tomography

Table 3: Diagnostic performance of DECT maps (qualitative assessment)

Parameter	Result (%)	95% confidence interval
True positive	56	NA
True negative	88	NA
False positive	3	NA
False negative	13	NA
Sensitivity	56/69=81.15	74.3–84.3
Specificity	88/91=96.70	91.5–99.1
Positive predictive value	56/59=94.91	87–98.6
Negative predictive value	88/101=87.12	82.5–89.3
Accuracy	90	84.1–92.7
Positive LR	24.61	8.7 –94.35
Negative LR	0.19	0.15–0.28

LR: Likelihood ratio, DECT: Dual-energy computed tomography

and specificity [12]. Our study, conducted in the acute phase of trauma, demonstrated higher sensitivity and specificity, suggesting that DECT VNCa is more accurate in the acute setting. Similarly, Ai *et al*. evaluated DECT and VNCa imaging for detecting bone bruises weeks after injury, finding moderate sensitivity [13]. In our study, DECT identified 59 out of 69 MRI-positive regions, reflecting an overall sensitivity of 81.15%.

Booz *et al*. reported high diagnostic accuracy for DECT VNCa reconstructions in depicting traumatic knee BME, with sensitivity and specificity similar to MRI [14]. Our qualitative analysis yielded comparable results, reinforcing DECT's diagnostic reliability. Wilson *et al*.'s meta-analysis confirmed DECT's high specificity and sensitivity for detecting BME in the appendicular skeleton, further supporting our findings [15].

The high diagnostic accuracy of DECT VNCa reconstructions indicates its diagnostic potential to consider it as an alternative imaging method for patients with acute knee trauma, particularly when MRI is unavailable or contraindicated. The ability to detect occult fractures more accurately compared to conventional grayscale CT further enhances DECT's clinical utility. Moreover, the shorter reconstruction time of DECT VNCa images compared to MRI can optimize workflow in acute trauma settings, reducing the need for additional imaging and potentially improving patient outcomes [16,17].

CONCLUSION

This study shows that third-generation DECT using VNCa techniques is a highly effective imaging modality for detecting BME in acute knee injuries, with superior diagnostic accuracy versus MRI. DECT has a sensitivity of 81.15% and a specificity of 96.70%, indicating that it is reliable in distinguishing genuine positives and true negatives, especially in acute settings. The ability of DECT to remove calcium from cancellous bone and provide unambiguous visual representation via color-coded maps increases its diagnostic value. This makes DECT a useful alternative to MRI, especially in emergency situations where MRI availability is limited or contraindicated. Moreover, the shorter reconstruction time and high diagnostic reliability of DECT can optimize workflow and improve patient outcomes. Consequently, DECT with VNCa techniques can play a crucial role in the early diagnosis and management of knee trauma, potentially preventing long-term complications and ensuring timely and appropriate therapeutic interventions.

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