ASIAN JOURNAL OF PHARMACEUTICAL AND CLINICAL RESEARCH

INNOVARE ACADEMIC SCIENCES
Knowledge to Innovation

Vol 17, Issue 9, 2024

Online - 2455-3891
Print - 0974-2441

Research Article

DETECTION OF BONE MARROW EDEMA IN VERTEBRAL COMPRESSION FRACTURES USING THIRD-GENERATION DUAL-ENERGY COMPUTED TOMOGRAPHY AND VIRTUAL NON-CALCIUM TECHNIQUES

TAPAS KUMAR SAHU[1], JEEVITHAN SHANMUGAM[2], GEETHANJALI SUNDARAM[3], SEETHARAMAN CANNANE*[4]

[1]Department of Radiology, KIMS Medical College, Bhubaneswar, Odisha, India. [2]Department of Community Medicine, KMCH Institute of Health Sciences and Research, Coimbatore, Tamil Nadu, India, [3]Department of Radiology, GKNM Hospital, Coimbatore, Tamil Nadu, India. [4]Department of Radiology, KMCH Institute of Health Sciences and Research, Coimbatore, Tamil Nadu, India.
*Corresponding author: Seetharaman Cannane; Email: drcseetharaman@gmail.com

Received: 12 May 2024, Revised and Accepted: 26 June 2024

ABSTRACT

Objectives: Vertebral compression fractures (VCFs) are a significant clinical concern worldwide, often resulting in increased morbidity and mortality. Malignancies, secondary osteoporosis, post-menopausal osteoporosis, and trauma are the most common causes of this. Early detection and appropriate treatment are crucial to alleviate pain, initiate therapy, prevent complications, and reduce the risk of new fractures. Various imaging modalities, including magnetic resonance imaging (MRI) and computed tomography (CT), are used to diagnose VCFs. However, MRI has limitations, and CT advancements, particularly dual-energy CT (DECT) with virtual non-calcium (VNCa) imaging, offer the best alternatives for detecting bone marrow edema.

Methods: This observational study was conducted at Kovai Medical Center and Hospital, Coimbatore, involving 46 adult patients with detectable VCFs. Approval was obtained from the Institutional Ethical and Scientific Committee, and informed consent was received from all participants. Patients underwent spine MRI and DECT on the same day. MRI was performed using Siemens 3T Skyra or Philips Ingenia 1.5T scanners, and DECT scans were taken using a third-generation 192-slice dual-source CT scanner. DECT images were processed to create VNCa images. Image analysis was conducted blindly, with MRI images showing increased STIR signal intensity and decreased T1 signal considered positive for bone marrow edema. DECT images were evaluated for edema presence.

Results: The study participants had a mean age of 58.65±15.47 years, with 54.3% females and 45.7% males. A total of 84 fractures were detected across 782 vertebral bodies, with 57.14% acute and 42.86% chronic. Fractures were evenly distributed between the dorsal (57.14%) and lumbar (42.86%) levels, predominantly at the dorsolumbar junction. Using the Genant grading system, fractures were classified into grades 0–3, with most fractures being grade 1 (35.7%) and grade 3 (35.7%). DECT demonstrated high diagnostic performance, with a sensitivity of 87.50%, specificity of 91.66%, positive predictive value of 93.33%, negative predictive value of 84.62%, and overall accuracy of 89.29%. The positive and negative likelihood ratios were 10.50–0.14, respectively.

Discussion: The study confirms that third-generation DECT with VNCa imaging is highly effective in detecting bone marrow edema in VCFs, showing diagnostic accuracy comparable to MRI. Previous studies corroborate these findings, indicating that DECT can serve as a reliable alternative, especially for patients with MRI contraindications. The advancements in DECT technology enhance its ability to differentiate and visualize bone marrow abnormalities, making it a valuable diagnostic tool in clinical practice.

Keywords: Vertebral compression fractures, Bone marrow edema, Dual-energy computed tomography, Magnetic resonance imaging, Virtual non-calcium imaging.

 DOI: http://dx.doi.org/10.22159/ajpcr.2024v17i9.52215. Journal homepage: https://innovareacademics.in/journals/index.php/ajpcr

INTRODUCTION

Vertebral compression fractures (VCFs) are a prevalent issue globally, contributing to reduced quality of life and heightened morbidity and mortality [1,2]. Malignancies, secondary osteoporosis, post-menopausal osteoporosis, and trauma are the most common causes of this [3]. Early detection and treatment are crucial for alleviating pain, initiating appropriate therapy, preventing complications, and reducing the risk of new fractures [4,5]. Despite the significance, VCFs are frequently underdiagnosed, and determining the fracture's age can be challenging without prior spinal imaging [6-11].

Various techniques, such as plain X-ray, magnetic resonance imaging (MRI), and bone scintigraphy, computed tomography (CT), can localize and characterize VCFs for timely treatment [12,13]. As MRI can pick up the fluid/edema or hemorrhage, it is the preferred way for detecting acute VCF [14-16]. However, MRI has limitations, including contraindications for some patients and the requirement for prolonged, still positioning, which may be difficult for those with back pain. CT, while less sensitive for dating fractures, offers advantages such as shorter scan times and better spatial resolution for detecting subtle cortical fractures [17-19]. Dual-energy CT (DECT) advancements have been utilized for visualizing bone marrow abnormalities directly by creating virtual non-calcium (VNCa) images, which allow for the detection of bone marrow edema [20-23].

Aim and objective

The aim and objective are to assess the diagnostic performance of a third-generation dual-energy CT VNCa technique for detecting bone marrow edema in patients with VCFs.

METHODS

This observational study was conducted in the Department of Radiology at Kovai Medical Center and Hospital, Coimbatore, a tertiary care hospital. Approval was obtained from the Institutional Ethical and

Scientific Committee, and written informed consent was received from all participants. The study included adult patients over 18 years of age who underwent spine MRI and had detectable VCF between June 2019 and May 2020. Exclusion criteria included general contraindications for MRI and/or CT, pathologic fractures due to tumor infiltration, and vertebral bodies with subtotal collapse.

All participants underwent spine MRI followed by DECT on the same day. MRI was performed using Siemens 3T Skyra or Philips Ingenia 1.5T scanners with dedicated phased array coils. The DECT scans were performed using a third-generation 192-slice dual-source CT scanner (Somatom Force; Siemens Healthcare). Post-processing of DECT images was performed using commercially available software (Syngo Via Dual Energy version VB30A; Siemens Healthcare) to create VNCa images.

Image analysis was conducted in a random order, blinded to MRI findings. MRI images showing increased signal intensity on STIR images and corresponding decreased signal on T1-weighted images were considered positive for bone marrow edema. DECT images were evaluated for the presence of shades of green–yellow to orange–red, indicating bone marrow edema.

RESULTS

Sociodemographic characteristics

The study participants were 46 patients with a mean age of 58.65±15.47 years. Most of the patients were aged between 61 and 80 years (50%), indicating that VCF is more prevalent in the older population. We observed a higher prevalence in females (54.3%) compared to males (45.7%). This distribution aligns with the understanding that osteoporosis, a major cause of VCF, is most commonly seen in the post-menopausal age group. Moreover, the fracture type distribution revealed that a significant proportion of patients had multiple fractures (47.8%), emphasizing the severity and recurrent nature of this condition in the affected demographic (Table 1).

Fracture characteristics

A total of 46 patients and 782 vertebral bodies were analyzed, revealing 84 fractures. The fracture characteristics data indicated that out of the total 84 fractures detected, 57.14% were acute and 42.86% were chronic. The distribution of fractures at different spinal levels showed an equal prevalence of fractures at the dorsal (57.14%) and lumbar (42.86%) levels. Notably, the dorsolumbar junction (D12-L1) was identified as a common site for these fractures, with D12 and L1 levels being particularly susceptible. The application of the Genant grading system further categorized the fractures into grades 0 to 3, with the majority classified as grade 1 (35.7%) and grade 3 (35.7%). This grading highlights the varied severity of fractures among the patients, with a substantial number exhibiting STIR hyperintensity, indicative of acute fractures (Table 2).

Diagnostic performance of DECT compared to MRI

The diagnostic performance analysis of DECT compared to MRI demonstrated high sensitivity (87.50%) and specificity (91.66%) in detecting bone marrow edema. The positive predictive value (PPV) was 93.33%, indicating that DECT is highly effective in confirming the presence of bone marrow edema when it is detected. The negative predictive value (NPV) of 84.62% suggests that DECT is also reliable in ruling out edema when it is not present. The overall diagnostic accuracy was 89.29%, reflecting the effectiveness of DECT in this context. The positive likelihood ratio (LR) of 10.50 and negative LR of 0.14 further support the robustness of DECT in diagnosing VCF, showing it a viable alternative to MRI, especially for patients with contraindications to MRI (Table 3).

Table 1: Sociodemographic characteristics of the study population

Sociodemographic parameter	Category	Frequency	Percent
Age distribution	<20 years	2	4.3
	21–40 years	8	17.4
	41–60 years	15	32.6
	61–80 years	23	50
	>80 years	2	4.3
	Mean±standard deviation		58.65±15.47 years
Gender distribution	Female	25	54.3
	Male	21	45.7
	Total	46	100
Fracture type	Single fracture	24	52.2
	Multiple fractures	22	47.8

Table 2: Fracture characteristics

Fracture characteristic	Category	Frequency	Percent
Acute versus chronic fractures	Acute	48	57.14
	Chronic	36	42.86
Fracture location	Dorsal level	48	57.14
	Lumbar level	36	42.86
Genant grading system	Grade 0	9	10.7
	STIR positive	7	
	STIR negative	2	
	Grade 1	30	35.7
	STIR positive	21	
	STIR negative	9	
	Grade 2	15	17.9
	STIR positive	7	
	STIR negative	8	
	Grade 3	30	35.7
	STIR positive	13	
	STIR negative	17	

Table 3: Diagnostic performance of dual-energy computed tomography compared to magnetic resonance imaging

Parameter	Result	95% Confidence interval
True positive	56	NA
True negative	88	NA
False positive	3	NA
False negative	13	NA
Sensitivity	42/48=87.50%	74.75–95.27%
Specificity	33/36=91.66%	77.53–98.25%
Positive predictive value	42/45=93.33%	82.50–97.65%
Negative predictive value	33/39=84.62%	72.11–92.13%
Accuracy	75/84=89.29%	80.63–94.98%
Positive LR	10.5	3.53–31.19
Negative LR	0.14	0.06–0.29

LR: Likelihood ratio

DISCUSSION

The study demonstrated that third-generation DECT with VNCa imaging has high diagnostic accuracy for diagnosing the edema in bone marrow by VCFs, comparable to MRI. This is consistent with previous studies that have shown DECT VNCa imaging to be effective in detecting bone marrow lesions across various anatomical regions [24-36]. The high sensitivity (87.50%) and specificity (91.66%) observed in our study underscore the robustness of DECT in identifying bone marrow edema, making it a viable alternative for patients with contraindications to MRI.

Pache *et al*. [24] and Guggenberger *et al*. [25] found that DECT was highly effective in detecting bone marrow edema with a diagnostic accuracy similar to that of MRI. Wang *et al*. [26] also demonstrated that DECT could detect bone marrow edema with high sensitivity and specificity. These studies corroborate our findings, indicating that DECT's advanced imaging capabilities, such as the use of a tin filter and dual-energy scanning modes, significantly enhance its ability to differentiate and visualize bone marrow abnormalities [27-36].

Our study's results are consistent with the diagnostic performance reported in these studies, further validating the utility of DECT in clinical practice. The NPV (84.62%) and PPV (93.33%) suggest that DECT is reliable in both confirming and ruling out bone marrow edema. The high diagnostic accuracy (89.29%) and favorable LRs (positive LR: 10.50 and negative LR: 0.14) reinforce the potential of DECT as an alternative modality for diagnosing VCF, especially for patients unable to undergo MRI.

CONCLUSION

The visual analysis of dual-energy VNCa color-coded images using third-generation DECT has shown splendid performance in detecting bone marrow edema in VCF. The latest advancements in DECT technology, including enhanced energy separation and material decomposition, offer a viable alternative imaging modality for patients with contraindications to MRI. Further studies with larger sample sizes are recommended to corroborate these findings and detect the full potential of DECT in various clinical scenarios.

REFERENCES

1. Cook DJ, Guyatt GH, Adachi JD, Clifton J, Griffith LE, Epstein RS, *et al*. Quality of life issues in women with vertebral fractures due to osteoporosis. Arthritis Rheum. 1993 Jun;36(6):750-6.
2. Center JR, Nguyen TV, Schneider D, Sambrook PN, Eisman JA. Mortality after all major types of osteoporotic fracture in men and women: An observational study. Lancet. 1999 Mar;353(9156):878-82.
3. Papaioannou A, Watts NB, Kendler DL, Yuen CK, Adachi JD, Ferko N. Diagnosis and management of vertebral fractures in elderly adults. Am J Med. 2002 Aug;113(3):220-8.
4. Longo UG, Loppini M, Denaro L, Maffulli N, Denaro V. Conservative management of patients with an osteoporotic vertebral fracture: A review of the literature. J Bone Joint Surg Br. 2012 Feb;94-B(2):152-7.
5. Body JJ, Bergmann P, Boonen S, Boutsen Y, Bruyere O, Devogelaer JP, *et al*. Non-pharmacological management of osteoporosis: A consensus of the Belgian Bone Club. Osteoporos Int. 2011 Nov;22(11):2769-88.
6. Heini PF, Wälchli B, Berlemann U. Percutaneous transpedicular vertebroplasty with PMMA: Operative technique and early results. A prospective study for the treatment of osteoporotic compression fractures. Eur Spine J. 2000 Oct 4;9(5):445-50.
7. Klazen CA, Lohle PN, de Vries J, Jansen FH, Tielbeek AV, Blonk MC, *et al*. Vertebroplasty versus conservative treatment in acute osteoporotic vertebral compression fractures (Vertos II): An open-label randomised trial. Lancet. 2010 Sep;376(9746):1085-92.
8. O'Neill TW, Felsenberg D, Varlow J, Cooper C, Kanis JA, Silman AJ. The prevalence of vertebral deformity in European men and women: The European vertebral osteoporosis study. J Bone Miner Res. 2009 Dec 3;11(7):1010-8.
9. Bazzocchi A, Spinnato P, Albisinni U, Battista G, Rossi C, Guglielmi G. A careful evaluation of scout CT lateral radiograph may prevent unreported vertebral fractures. Eur J Radiol. 2012 Sep;81(9):2353-7.
10. Francis RM, Aspray TJ, Hide G, Sutcliffe AM, Wilkinson P. Back pain in osteoporotic vertebral fractures. Osteoporos Int. 2008 Jul;19(7):895-903.
11. Link TM. Osteoporosis imaging: State of the art and advanced imaging. Radiology. 2012 Apr;263(1):3-17.
12. Williams AL, Al-Busaidi A, Sparrow PJ, Adams JE, Whitehouse RW. Under-reporting of osteoporotic vertebral fractures on computed tomography. Eur J Radiol. 2009 Jan;69(1):179-83.
13. Old JL, Calvert M. Vertebral compression fractures in the elderly. Am Fam Physician. 2004 Jan 1;69(1):111-6.
14. Pizones J, Izquierdo E, Álvarez P, Sánchez-Mariscal F, Zúñiga L, Chimeno P, *et al*. Impact of magnetic resonance imaging on decision making for thoracolumbar traumatic fracture diagnosis and treatment. Eur Spine J. 2011 Aug;20(S3):390-6.
15. Qaiyum M, Tyrrell PN, McCall IW, Cassar-Pullicino VN. MRI detection of unsuspected vertebral injury in acute spinal trauma: Incidence and significance. Skelet Radiol. 2001 Jun 1;30(6):299-304.
16. Mandalia V, Henson JH. Traumatic bone bruising-a review article. Eur J Radiol. 2008 Jul;67(1):54-61.
17. Piazzolla A, Solarino G, Lamartina C, De Giorgi S, Bizzoca D, Berjano P, *et al*. Vertebral bone marrow edema (VBME) in conservatively treated acute vertebral compression fractures (VCFs): Evolution and clinical correlations. Spine. 2015 Jul;40(14):E842-8.
18. Memarsadeghi M, Breitenseher MJ, Schaefer-Prokop C, Weber M, Aldrian S, Gäbler C, *et al*. Occult scaphoid fractures: Comparison of multidetector CT and MR imaging-initial experience. Radiology. 2006 Jul;240(1):169-76.
19. Carberry GA, Pooler BD, Binkley N, Lauder TB, Bruce RJ, Pickhardt PJ. Unreported vertebral body compression fractures at abdominal multidetector CT. Radiology. 2013 Jul;268(1):120-6.
20. Frellesen C, Azadegan M, Martin SS, Otani K, D'Angelo T, Booz C, *et al*. Dual-energy computed tomography-based display of bone marrow edema in incidental vertebral compression fractures: Diagnostic accuracy and characterization in oncological patients undergoing routine staging computed tomography. Invest Radiol. 2018 Jul;53(7):409-16.
21. Vela JH, Wertz CI, Onstott KL, Wertz JR. Trauma imaging: A literature review. Radiol Technol. 2017 Jan;88(3):263-76.
22. Boks SS, Vroegindeweij D, Koes BW, Hunink MG, Bierma-Zeinstra SM. Follow-up of occult bone lesions detected at MR imaging: Systematic review. Radiology. 2006 Mar;238(3):853-62.
23. Thomas C, Schabel C, Krauss B, Weisel K, Bongers M, Claussen CD, *et al*. Dual-energy CT: Virtual calcium subtraction for assessment of bone marrow involvement of the spine in multiple myeloma. Am J Roentgenol. 2015 Mar;204(3):W324-31.
24. Pache G, Krauss B, Strohm P, Saueressig U, Blanke P, Bulla S, *et al*. Dual-energy CT virtual noncalcium technique: Detecting posttraumatic bone marrow lesions-feasibility study. Radiology. 2010 Aug;256(2):617-24.
25. Guggenberger R, Gnannt R, Hodler J, Krauss B, Wanner GA, Csuka E, *et al*. Diagnostic performance of dual-energy CT for the detection of traumatic bone marrow lesions in the ankle: Comparison with MR imaging. Radiology. 2012 Jul;264(1):164-73.
26. Wang CK, Tsai JM, Chuang MT, Wang MT, Huang KY, Lin RM. Bone marrow edema in vertebral compression fractures: Detection with dual-energy CT. Radiology. 2013 Nov;269(2):525-33.
27. Reagan AC, Mallinson PI, O'Connell T, McLaughlin PD, Krauss B, Munk PL, *et al*. Dual-energy computed tomographic virtual noncalcium algorithm for detection of bone marrow edema in acute fractures: Early experiences. J Comput Assist Tomogr. 2014;38(5):802-5.
28. Reddy T, McLaughlin PD, Mallinson PI, Reagan AC, Munk PL, Nicolaou S, *et al*. Detection of occult undisplaced hip fractures with a dual-energy CT algorithm targeted to detection of bone marrow edema. Emerg Radiol. 2015 Feb;22(1):25-9.
29. Bierry G, Venkatasamy A, Kremer S, Dosch JC, Dietemann JL. Dual-energy CT in vertebral compression fractures: Performance of visual and quantitative analysis for bone marrow edema demonstration with comparison to MRI. Skeletal Radiol. 2014 Apr;43(4):485-92.
30. Cao J, Wang Y, Kong X, Yang C, Wang P. Good interrater reliability of a new grading system in detecting traumatic bone marrow lesions in the knee by dual energy CT virtual non-calcium images. Eur J Radiol. 2015 Jun;84(6):1109-15.
31. Dareez NM, Dahlslett KH, Engesland E, Lindland ES. Scaphoid fracture: Bone marrow edema detected with dual-energy CT virtual non-calcium images and confirmed with MRI. Skeletal Radiol. 2017 Dec;46(12):1753-6.
32. Karaca L, Yuceler Z, Kantarci M, Çakır M, Sade R, Calıkoglu C, *et al*. The feasibility of dual-energy CT in differentiation of vertebral compression fractures. Br J Radiol. 2016 Jan;89(1057):20150300.
33. Petritsch B, Kosmala A, Weng AM, Krauss B, Heidemeier A, Wagner R, *et al*. Vertebral compression fractures: Third-generation dual-energy CT for detection of bone marrow edema at visual and quantitative analyses. Radiology. 2017 Feb 27;284(1):161-8.
34. Foti G, Beltramello A, Catania M, Rigotti S, Serra G, Carbognin G. Diagnostic accuracy of dual-energy CT and virtual non-calcium techniques to evaluate bone marrow edema in vertebral compression fractures. Radiol Med. 2019 Jun;124(6):487-94.
35. Gehlbach SH, Bigelow C, Heimisdottir M, May S, Walker M, Kirkwood JR. Recognition of vertebral fracture in a clinical setting. Osteoporos Int. 2000 Aug 1;11(7):577-82.
36. Delmas PD, van de Langerijt L, Watts NB, Eastell R, Genant H, Grauer A, *et al*. Underdiagnosis of vertebral fractures is a worldwide problem: The IMPACT study. J Bone Miner Res. 2004 Dec 6;20(4):557-63.