Review Article

Imaging of vertebral fractures

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ABSTRACT

Vertebral fracture is a common clinical problem. Osteoporosis is the leading cause of non-traumatic vertebral fracture. Often, vertebral fractures are not clinically suspected due to nonspecific presentation and are overlooked during routine interpretation of radiologic investigations. Moreover, once detected, many a times the radiologist fails to convey to the clinician in a meaningful way. Hence, vertebral fractures are a constant cause of morbidity and mortality. Presence of vertebral fracture increases the chance of fracture in another vertebra and also increases the risk of subsequent hip fracture. Early detection can lead to immediate therapeutic intervention improving further the quality of life. So, in this review, we wish to present a comprehensive overview of vertebral fracture imaging along with an algorithm of evaluation of vertebral fractures.

Key words: Diagnosis, imaging, osteoporosis, radiography, vertebral fractures

Introduction

Osteoporosis, defined as a clinical condition characterised by a "low bone mass and micro-architectural deterioration of bone tissue leading to decreased bone strength and an increased susceptibility to fractures" is a major global health problem affecting an increasing number of women and men beyond 50 years of age.[1] Among the various insufficiency fractures associated with osteoporosis, vertebral fractures are the commonest and the earliest seen fractures. It has been estimated that about 20-25% Caucasian women and men above 50 years have a prevalent vertebral fracture and there is a steadily increasing upward trend in incidence of vertebral fractures with age.[2-5] Data from population studies on Indian women have reported a similar 17% prevalence of vertebral fractures.[6] Also, unique issues like under-nutrition, dietary vitamin D deficiency, lack of adequate awareness and health-care access augment the burden induced by vertebral fractures in Asia.[7]

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Clinical importance

Studies have also shown that vertebral fractures are an important predictor of subsequent insufficiency fractures in osteoporosis. The presence of one vertebral fracture confers a 5 to 12.6 times risk of subsequent vertebral fractures and a 2.3-3.4 times risk of hip fractures.[8,9] It has also been shown that among women with one vertebral fracture, about 20% will go on to develop another vertebral fracture within a year, with 4 times increased risk in women with severe osteoporotic fractures and 3 times increased risk in women with multiple vertebral fractures.[10] Vertebral fractures are also associated with back pain, physical deformity, decline in social function, loss of self-esteem, impaired quality of life and increased morbidity and mortality.[8,11-16] At the same time, with advances in treatment of osteoporosis, detection and early initiation of treatment with bisphosphonates and selective estrogen receptor modulators like raloxifene can reduce the risk of vertebral and other insufficiency fractures by 40-65% and mitigate the subsequent morbidity and mortality associated with them.[17-20]

Unfortunately, despite the critical importance of detecting vertebral fractures, these fractures remain under-diagnosed. Only one in four vertebral fractures is detected clinically

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because symptoms do not correlate well with underlying fractures.[21] Another fallacy in diagnosis is that insufficiency fractures are clinically associated with pain and limitation of movement which are also chronically present in many osteoporotic patients and these patients do not report to the hospital in an acute setting.[21-23] A "missed-diagnosis" rate on radiology is also high, as only about 50% of contemporaneous radiology reports mentioned these vertebral fractures.[24-26] In a study by Gehlbach *et al*.,[24] among 934 elderly women undergoing chest X-ray on hospital admission, 132 women retrospectively had vertebral collapse. However, this was mentioned in medical records or discharge summaries of only 17% of these 132 women, thus representing a major missed opportunity for intervention and treatment. Similarly, in the study by Majumdar *et al*.,[26] vertebral fractures were reported in only 60% in radiology reports and only 25% received further treatment for osteoporosis. This under-diagnosis of vertebral fractures is a worldwide problem with a global rate of under-diagnosis being 34%.[27] Evidently "missed" vertebral fractures on imaging represent a major missed opportunity for early intervention and treatment. The "missed diagnosis" stems from the lack of awareness of radiological appearances of vertebral fractures, lack of standardised assessment and the general ambiguity in description and terminology.[22,23,28,29]

Thus, in this article we describe the radiographic assessment of osteoporotic vertebral fractures, the role of CT and MRI in vertebral fractures, briefly enumerate the role of Dual Energy X-ray Absorptiometry (DEXA) scan and highlight a standardised vertebral fracture assessment and reporting technique.

Radiographic assessment of vertebral fractures

Radiography, comprising of anteroposterior and lateral views of dorsolumbar spine, is the cornerstone for detecting vertebral fractures. Anteroposterior views are generally obtained once at baseline to enable accurate counting of the vertebrae while subsequent lateral radiographs are sufficient for follow-up and serial assessment. It is important to assess the mid-dorsal and the dorsolumbar region as most compression fractures occur at D7-D8 and D12-L1 regions.[22,23] While obtaining a lateral radiograph, ensure that spine is parallel to the film during patient positioning and dorsal and lumbar radiographs are obtained separately with centering at D7 and L3 for dorsal and lumbar spine radiographs respectively to avoid misinterpretation induced by scoliosis, obliquity and false biconcave appearance of vertebral end-plates known as "bean-can effect" [Figure 1].[23]

In a normal and properly obtained radiograph, the end-plates are horizontal and there is similarity in vertebral shape and size among contiguous levels [Figure 2]. Any loss of height more than 20% of vertebra, presence of end-plate deformities and altered appearance of the vertebra should be considered as a fracture and further assessed.[29] Various visual qualitative as well as quantitative assessment methods for identifying vertebral fractures have been described by authors like Smith *et al*.,[30] Barrnet and Nordin,[31] Kleerekoper *et al*.,[32] and Hurxthal *et al*.,[33] to name a just few. Quantitative assessment methods known as vertebral morphometry are based upon strict six-point placement either manually or using specialised software. However; these are restricted to research purposes and are not easily amenable for daily, clinical use.[34,35] Thus, the most widely used and consistently ratified grading scale for vertebral fractures is the visual semi-quantitative assessment method described by Genant *et al*.[36]

Genant visual semi-quantitative assessment method

In Genant's visual semiquantitative assessment, severity of vertebral fracture is assessed by visual determination of the extent of a vertebral height reduction and morphologic change. Thoracic and lumbar vertebrae from D4 to L4 are visually inspected and graded as normal (grade 0), mildly deformed (grade 1: reduction of 20-25% of height and 10-20% of projected vertebral area), moderately deformed (grade 2: reduction of 26-40% of height and 21-40% of projected vertebral area), and severely deformed (grade 3: reduction of >40% of height and projected vertebral area) [Figures 3 and 4]. Unlike the other visual approaches the shape of the vertebral deformity (wedge, biconcavity or crush) is no longer linked to the grading of a fracture in this approach. But at the same time, any alterations in the shape and configuration of the vertebrae relative to adjacent vertebrae are mentioned to add a qualitative aspect to the overall interpretation.[35] Since reduction of the vertebral height is visually estimated without any measurement, this method is called a semi-quantitative method. A "spinal

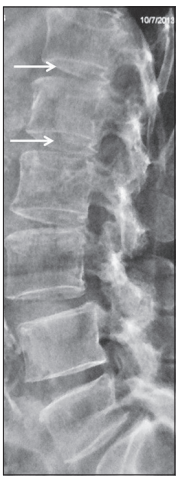

Figure 1: Lateral radiograph of lumbar spine shows "bean-can" appearance of vertebral end-plates (arrow). This is due to oblique positioning and should not be mistaken for fracture/deformity

fracture index" can be calculated from this semi-quantitative assessment as the sum of all grades assigned to the vertebrae divided by the number of the evaluated vertebrae. Higher the number of vertebrae involved, greater is the risk of progression and further osteoporotic fractures in the future.

The advantages of Genant's method are that is easy to implement in daily practice, more standardised than purely qualitative methods,[37,38] less cumbersome than quantitative methods and can be used by both experienced and novice readers with a fair degree of reproducibility and accuracy.[29,39] Studies have also shown moderate to good correlation between Genant's semi-quantitative and quantitative methods especially for moderate to severe fractures.[39-41] The chief limitation of Genant's method includes difficulty in differentiating normal anterior wedging in mid-thoracic vertebrae and thoracolumbar vertebrae in women and men respectively from early Grade 1 osteoporotic collapse. However, this can be overcome by readers' experience, using serial radiographs for evaluation and comparison and by also estimating the bone mineral density (BMD) as mild vertebral fractures are usually associated with decreased BMD.[42,43]

Along with presence of vertebral fractures, the age of the fracture should also be assessed to determine whether the present fracture is responsible for current symptoms of the patient. On conventional radiographs, it is often difficult to determine the age of the fracture unless prior radiographs are available for comparison. If there is cortical disruption or impaction of the trabeculae, then the diagnosis of acute fracture is obvious. In the absence of these features, the fracture is generally considered to be chronic. However many times, such a clear-cut differentiation is not possible. MRI and nuclear scan can help in such cases as lack of edema on MRI [Figures 5 and 6] and lack of radiotracer uptake on a bone scan indicate an old fracture.[29]

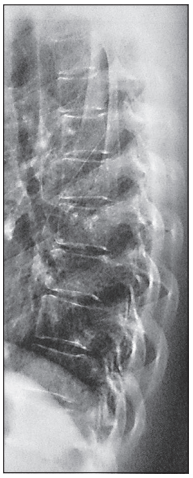

Figure 2: Normal spine. Lateral radiograph of spine shows osteopenia. But vertebral end-plates are horizontal with similar size and shape. No evidence of vertebral fractures

Differential diagnoses of vertebral fractures

Besides osteoporosis, vertebral fractures are also seen in

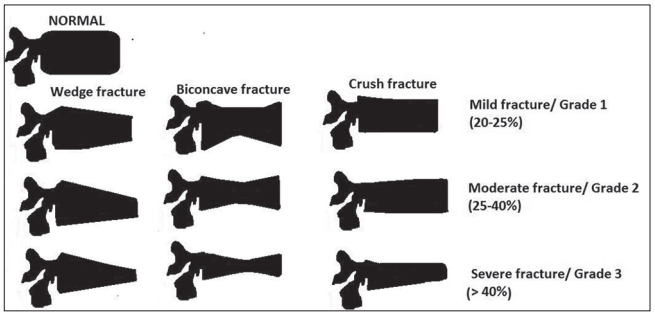

Figure 3: Schematic diagram to represent Genant's semi-quantitative method of assessment

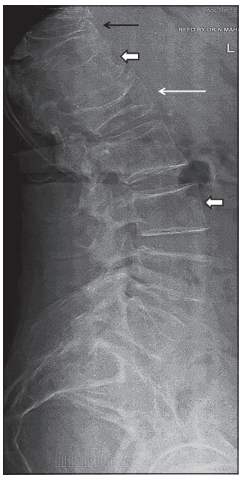

Figure 4: Lateral radiograph of lumbar spine shows osteopenia with severe/Grade 3 fracture in L1 vertebra (white arrow). Morphologically fracture is biconcave in appearance. Mild/Grade 1 crush type fractures also noted in adjacent L2 and L3 vertebrae (black arrow)

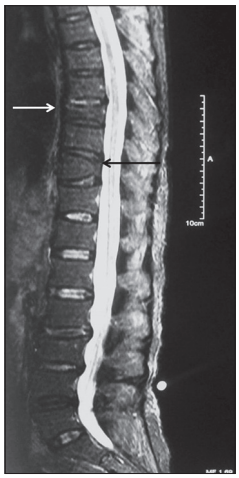

Figure 5: Sagittal T2 W MR image of spine shows moderate/grade 2 fracture in D10 and severe/grade 3 fracture in D8 (arrows) with maintained marrow signal intensity. There is no hyperintensity or bone marrow edema on T2 W image suggestive of chronic fractures

osteomalacia, osteoporosis secondary to glucocorticoid intake, hyperparathyroidism, chronic kidney disease, post-trauma, multiple myeloma and metastases. Thus, the radiograph should also be assessed for presence of other features which would favour a pathologic fracture and necessitate further diagnostic workup with MRI or nuclear scan. A reduction in bone density, accentuated secondary or vertical trabeculations giving a striated appearance and sharply outlined cortical end-plates are radiologic signs of osteoporosis and can be used to differentiate osteoporotic fractures from non-osteoporotic fractures [Figure 7].[23,44]

In osteomalacia, the bones being soft, the end-plates are deformed and fuzzy giving a biconcave appearance. In glucocorticoid induced osteoporosis, end-plate sclerosis can be seen in extreme cases due to callus formation and marginal condensation. Vertebral fractures in hyperparathyroidism are usually associated with other signs of hyperparathyroidism on skeletal survey such as subperiosteal resorption, cortical tunnelling and brown tumours and occasionally soft tissue calcifications. In chronic kidney disease, the vertebrae have a rugger-jersey appearance due to endplate sclerosis and central osteopenia [Figure 8]. However, post-traumatic fractures are difficult to differentiate form osteoporotic collapse in absence of positive history and associated hematoma. In multiple myeloma, there are multiple lytic lesions along with osteopenia and vertebral fracture is associated with a soft tissue component. Similarly, location of fracture above D7, presence of soft-tissue component, convex bulge in posterior cortex of vertebral body and involvement of posterior elements of the spine favour metastatic/malignant vertebral fracture.[44] Also newer imaging techniques like MRI and nuclear scan can help in differentiating benign osteoporotic collapse from malignant fractures as described subsequently.[23]

Vertebral fractures also need to be differentiated from normal variants like limbus vertebra, cupid-bow appearance and vertebral deformities such as H-shaped vertebra in sickle cell anemia, Gaucher's disease, congenital anomalies like block vertebra, osteochondritis and degenerative spondylosis [Figure 9]. In osteochondritis, namely Scheuermann's disease, there is anterior wedging of multiple adjacent vertebrae, end-plate irregularity with Schmorl's nodes and kyphosis. Spondylosis is characterised by end-plate sclerosis, marginal osteophytes and decreased inter-vertebral disc spaces along with anterior wedging. An algorithm-based qualitative (ABQ) method has been described to differentiate osteoporotic vertebral fractures from vertebral deformities with "short vertebral height" by Jiang *et al*.[45] However, this method needs further evaluation and validation with the widely established semi-quantitative method before it can be put to daily practice.[45,46] Thus, to

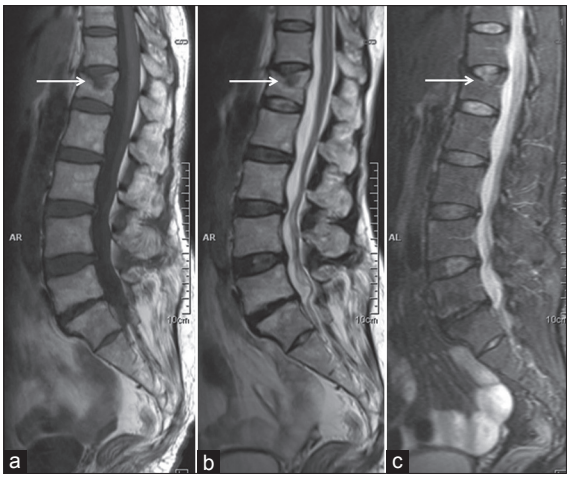

Figure 6: Sagittal T1 W (a), T2 W (b) and STIR (c) MR images of spine show moderate/grade 2 fracture in D12 (arrow) without any edema suggestive of chronic fracture

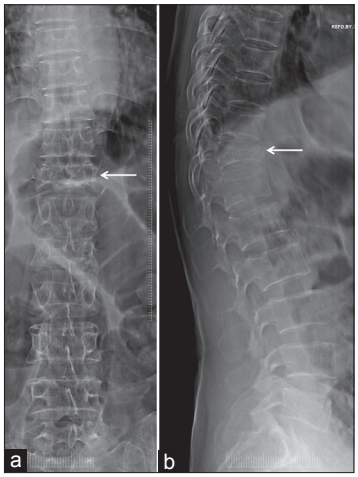

Figure 7: Lateral radiograph of spine shows characteristics of osteoporotic fracture. Severe/grade 3 fracture noted in D11 vertebra (arrow). Other vertebrae show prominent vertical trabeculae and sharply outline cortical end-plates

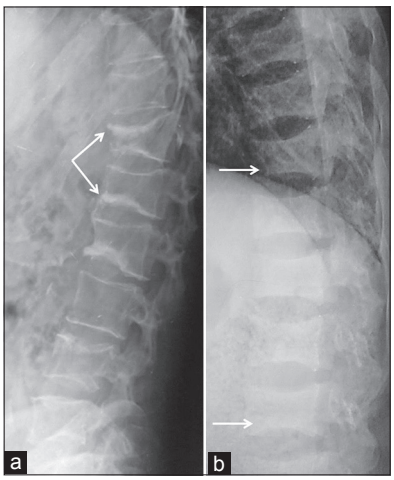

Figure 8: Non osteoporotic vertebral fractures. (a) Lateral radiograph of spine in a patient with Cushing's syndrome shows multiple fractures with sclerosis of end-plates (arrow). (b) Lateral radiograph of spine in a patient with chronic kidney disease and secondary hyperparathyroidism shows biconcave appearance in multiple vertebrae and increased density at end-plates and relatively radiolucent central part suggestive of rugger-jersey spine (arrows)

sum up the chief advantage of radiography for detecting vertebral fractures is the easy availability of the technique while potential limitations include missed diagnoses and misinterpretation due to lack of experience, confusion with anatomical variants or other pathological conditions and inability to clearly distinguish acute from chronic fractures.

Computed tomography in vertebral fractures

With the widespread availability and use of Multidetector CT (MDCT), many fractures can be incidentally detected on routine sagittal reformations in patients undergoing CT scans for other indications [Figure 10].[47] However, despite the ease of identifying vertebral fractures in CT, many fractures still don't get reported because of assessment of vertebrae in axial sections only instead of sagittal sections.[48] CT, because of its superior ability to depict bone as compared to radiographs, can also better detect cortical bone destruction and involvement of posterior elements of spine thus distinguishing benign from malignant fractures and acute versus chronic fractures. CT can also better depict intraosseous air or "vacuum cleft sign" which is a reliable indicator of benign fracture.[49] However, routine use of CT for detecting fractures is not practical due to its high radiation burden and cost and is considered a potential limitation of CT. Use of only lateral scout CT images has been proposed to be a reasonable middle path, thereby retaining the superior resolution of CT at a much lesser radiation dose.[50] Other uses of CT include microCT (μCT) and quantitative CT (qCT) that can directly assess BMD, cortical as well as trabecular bone microarchitecture at a lesser radiation dose due to their high spatial resolution. These techniques are still under evaluation and are currently restricted to research and follow-up in osteoporosis drug trails and are not amenable for reporting of osteoporotic fractures in daily clinical practice.[44,51-53]

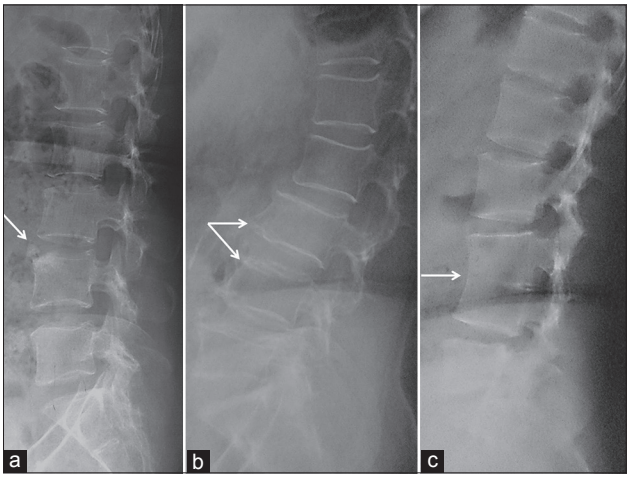

Figure 9: Vertebral deformities. Lateral radiographs of spine show limbus vertebra (a), degenerative spondylosis (b) and block vertebrae (c). These should not be mistaken for fractures. In degenerative sponylosis (b), the decrease in height is less than 20% and parallelism of end-plates is maintained

Magnetic resonance imaging in vertebral fractures

MRI chiefly serves as a problem-solving modality to differentiate benign from malignant fractures. However recent advances in MRI techniques, use of higher field strengths andnewer sequences have expanded the role of MRI to analysis of trabecular bone structure in peripheral skeleton and functional bone marrow imaging using diffusion weighted imaging (DWI), Dynamic contrast enhanced MR perfusion (DCE-MRI) and MR spectroscopy (MRS).[51,52]

The various morphologic signs of benign fracture include a) maintenance of at least some normal marrow signal b) no involvement of the posterior elements c) fluid sign or gas within the vertebral body[54] d) low intensity band along the fractured endplate representing the fracture line e) lack of discrete soft tissue mass either in paravertebral or epidural location f) fracture not involving cervical or upper dorsal (D1-D5) vertebrae g) no restriction of diffusion on DWI h) signal drop in opposed phase images compared to in-phase images on chemical shift imaging (CSI).[23,55] Conversely, altered signal intensity in non-fractured vertebrae, diffuse signal alteration in fractured vertebrae including posterior elements, and restricted diffusion strongly favour malignant etiology [Figure 11].[56]

In osteoporosis, various researchers have pursued the link between increase in bone marrow fat with decrease in bone density using MRS and perfusion techniques and have found that there is a reliable increase in marrow fat content on MRS and decrease in bone marrow perfusion with progressive decline in bone mineral density.[57-59] Similarly; Tang *et al*.,[60] found a positive correlation between T-scores of BMD and Apparent Diffusion Coefficient (ADC) values in DWI implying increasingly free diffusion with decrease in BMD and increase in vertebral marrow fat. Thus, while

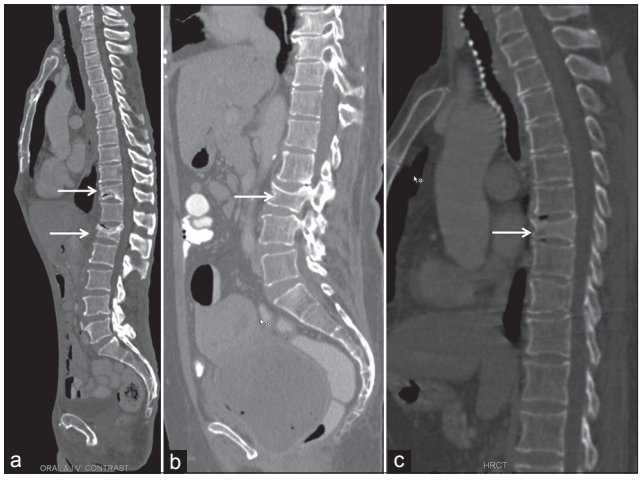

Figure 10: MDCT sagittal reformatted images in three different patients undergoing abdominal CT scans for other indications clearly show incidentally detected multiple vertebral fractures (arrows)

MRI is an excellent in differentiating benign from malignant vertebral fractures and has research applications, limitations include restricted availability, expense and relative lack of expertise in acquiring and interpreting scans.

DEXA and nuclear medicine in vertebral fractures

Fan- beam dual-energy X-ray absorptiometry (DEXA) systems can be used to obtain lateral and anteroposterior views of the dorsolumbar spine to assess for presence of fractures which is called as Vertebral Fracture Assessment (VFA). VFA can be easily merged with densitometry at the same sitting time and testing point. The same semi-quantitative technique and morphometric techniques used for radiographs can be applied to DEXA systems with good accuracy and reproducibility for moderate to severe fractures.[61-63] DEXA has been found to be equivalent to radiographs for detecting grade 2 and grade 3 fractures.[61] Thus, VFA provides a reasonable alternative to radiographs at lesser radiation dose and cost.[64] The relative disadvantage of DEXA included inferior visualisation and poor resolution above D7 vertebra which have now been overcome by newer scanners.

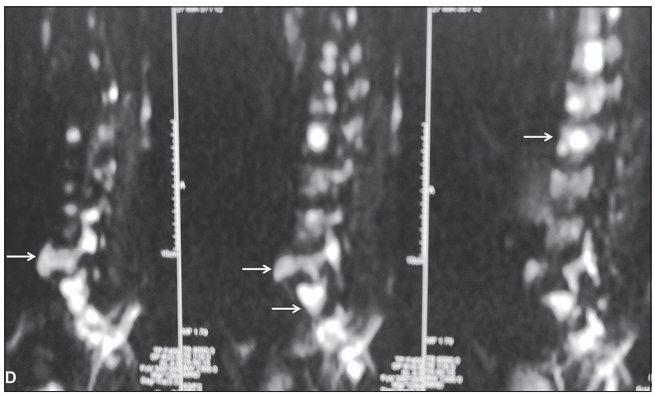

Figure 11: Pathological fracture in patient with multiple myeloma. Sagittal T1 W (a), T2 W (b) and post-contrast (c) MR images show severe fracture at L5 level with complete vertebral collapse and soft tissue component bulging posteriorly causing compression of cauda equina (arrow). Multiple other vertebrae show altered signal intensity and enhancement. Diffusion weighted images obtained at b-value of 1000 (d) show restricted diffusion at L5 and in sacrum and in other lumbar vertebrae

The International Society for Clinical Densitometry that defines guidelines for indications of VFA, currently states that VFA is best suited for assessment of patients with high pre-test probability of vertebral fractures[65] and in whom detection of fractures will affect or alter therapy.[64] At the same time, any equivocal results on VFA should be correlated with radiographs especially since VFA is less suited for detection of mild fractures.

Lastly, nuclear medicine using FDG-PET scans can also determine the benign versus malignant etiology of vertebral fractures, when MRI is either equivocal or contraindicated. In a study by Cho *et al*.,[66] using a Standardised Uptake Value (SUV) cut off as 4.25, FDG-PET could identify malignant vertebral fractures with a sensitivity of 85% and specificity of 71%. While malignant fractures show higher radiotracer uptake, benign osteoporotic fractures are not associated with significant radiotracer uptake even in acute stage.[67-69] Also, in suspected malignant etiology, nuclear medicine can detect multiple other sites of metastases [Figure 12]. The chief

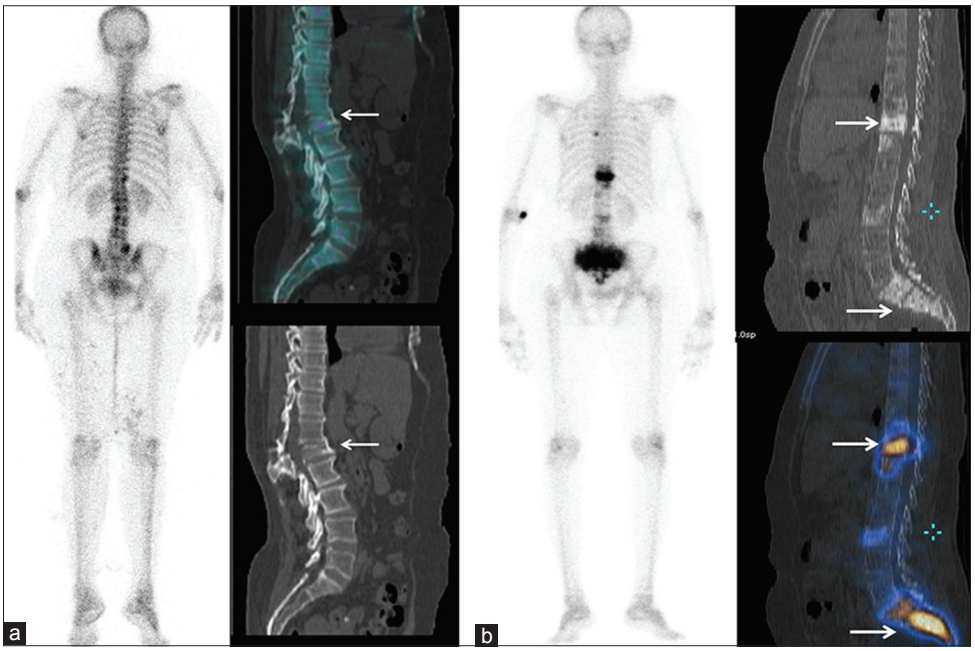

Figure 12: FDG-PET images (A) in a patient with mild/grade 1 fracture in L1 vertebra do not show any significant radiotracer uptake suggestive of osteoporotic fracture. FDG-PET images in a patient with pathological fractures (B) show multiple areas of radiotracer uptake in sacrum and D10 vertebrae (arrows). L3 vertebra is sclerotic but without any uptake, likely osteoporotic fracture

limitation of FDG-PET is its relatively low specificity as even benign non-osteoporotic fractures like post-traumatic and post-infectious fractures can show FDG uptake. Thus, being a relatively emerging modality, more studies are needed to validate differentiation between benign osteoprotic, benign non-osteoporotic and malignant vertebral fractures.

Conclusion

It is imperative to detect osteoporotic vertebral fractures to initiate early therapy. Vertebral fractures are strongly predictive of subsequent insufficiency fractures. While many vertebral fractures can be clinically silent, radiographs are a good modality to detect them with VFA using DEXA providing an excellent alternative. Figure 13 provides an algorithmic approach to detection of vertebral fractures. Using a standardised approach and semi-quantitative technique for evaluation, it is feasible to detect vertebral fractures. Radiologic reports should clearly mention the presence, site and number of fractures without any hedging or ambiguity to avoid delaying effective treatment strategies. While CT can also fortuitously detect vertebral fractures, MRI and nuclear medicine mainly serve as problem solving modalities to determine the age and etiology of vertebral fractures.

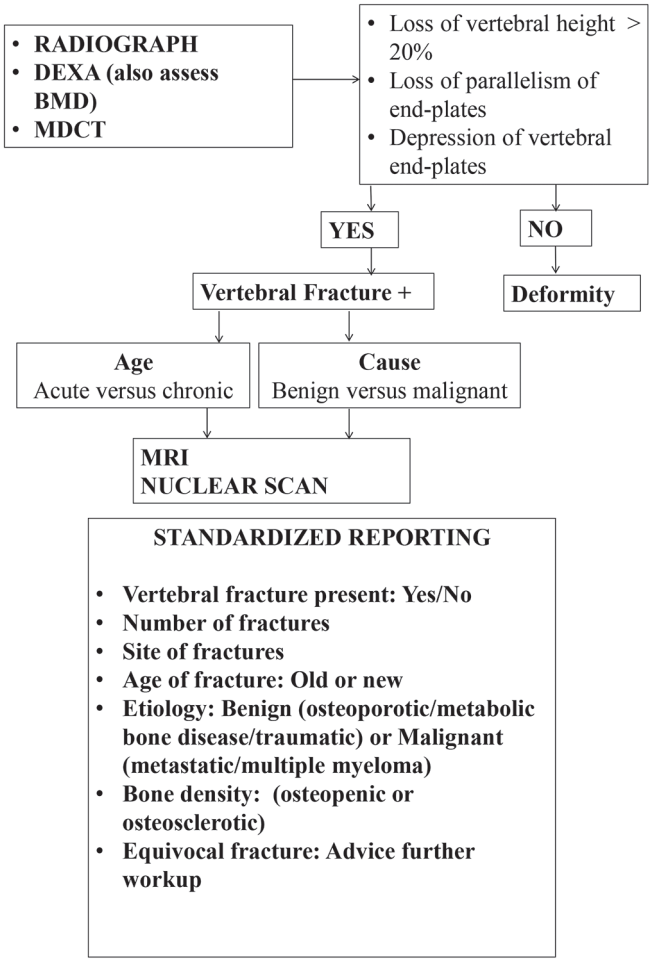

Figure 13: An algorithmic approach to vertebral fractures in routine practice

References

1. Prevention and management of osteoporosis. World Health Organ Tech Rep Ser 2003;921:1-164.
2. Felsenberg D, Silman AJ, Lunt M, Armbrecht G, Ismail AA, Finn JD, *et al*.; European Prospective Osteoporosis Study (EPOS) Group. Incidence of vertebral fracture in Europe: Results from the European Prospective Osteoporosis Study (EPOS). J Bone Miner Res 2002;17:716-24.
3. Cooper C, O'Neill T, Silman A. The epidemiology of vertebral fractures. European Vertebral Osteoporosis Study Group. Bone 1993;14:S89-97.
4. 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 1996;11:1010-8.
5. Haczynski J, Jakimiuk A. Vertebral fractures: A hidden problem of osteoporosis. Med Sci Monit 2001;7:1108-17.
6. Marwaha RK, Tandon N, Gupta Y, Bhadra K, Narang A, Mani K, *et al*. The prevalence of and risk factors for radiographic vertebral fractures in older Indian women and men: Delhi Vertebral Osteoporosis Study (DeVOS). Arch Osteoporos 2012;7:201-7.
7. Mithal A, Kaur P. Osteoporosis in Asia: A call to action. Curr Osteoporos Rep 2012;10:245-7.
8. Ross PD. Clinical consequences of vertebral fractures. Am J Med 1997;103:30S-42; discussion 42S-3.
9. Melton LJ 3rd, Atkinson EJ, Cooper C, O'Fallon WM, Riggs BL. Vertebral fractures predict subsequent fractures. Osteoporos Int J 1999;10:214-21.
10. Lindsay R, Silverman SL, Cooper C, Hanley DA, Barton I, Broy SB, *et al*. Risk of new vertebral fracture in the year following a fracture. JAMA 2001;285:320-3.
11. O'Neill TW, Cockerill W, Matthis C, Raspe HH, Lunt M, Cooper C, *et al*. Back pain, disability, and radiographic vertebral fracture in European women: A prospective study. Osteoporos Int J 2004;15:760-5.
12. Lips P, van Schoor NM. Quality of life in patients with osteoporosis. Osteoporos Int J 2005;16:447-55.
13. Oleksik AM, Ewing S, Shen W, van Schoor NM, Lips P. Impact of incident vertebral fractures on health related quality of life (HRQOL) in postmenopausal women with prevalent vertebral fractures. Osteoporos Int J 2005;16:861-70.
14. Kado DM, Browner WS, Palermo L, Nevitt MC, Genant HK, Cummings SR. Vertebral fractures and mortality in older women: A prospective study. Study of Osteoporotic Fractures Research Group. Arch Intern Med 1999;159:1215-20.
15. Cooper C. The crippling consequences of fractures and their impact on quality of life. Am J Med 1999;103:12S-7; discussion 17S-9.
16. Cockerill W, Lunt M, Silman AJ, Cooper C, Lips P, Bhalla AK, *et al*. Health-related quality of life and radiographic vertebral fracture. Osteoporos Int J 2004;15:113-9.
17. Sambrook P, Cooper C. Osteoporosis. Lancet 2006;367:2010-8.
18. Black DM, Thompson DE, Bauer DC, Ensrud K, Musliner T, Hochberg MC, *et al*. Fracture risk reduction with alendronate in women with osteoporosis: The Fracture Intervention Trial. FIT Research Group. J Clin Endocrinol Metab 2000;85:4118-24.
19. Schwartz AV, Bauer DC, Cummings SR, Cauley JA, Ensrud KE, Palermo L, *et al*. Efficacy of continued alendronate for fractures in women with and without prevalent vertebral fracture: The FLEX trial. J Bone Miner Res 2010;25:976-82.

20. Akesson K. New approaches to pharmacological treatment of osteoporosis. Bull World Health Organ 2003;81:657-64.
21. Fink HA, Milavetz DL, Palermo L, Nevitt MC, Cauley JA, Genant HK, *et al*. What proportion of incident radiographic vertebral deformities is clinically diagnosed and vice versa? J Bone Miner Res 2005;20:1216-22.
22. Grigoryan M, Guermazi A, Roemer FW, Delmas PD, Genant HK. Recognizing and reporting osteoporotic vertebral fractures. Eur Spine J 2003;12:S104-12.
23. Griffith JF, Guglielmi G. Vertebral fracture. Radiol Clin North Am 2010;48:519-29.
24. Gehlbach SH, Bigelow C, Heimisdottir M, May S, Walker M, Kirkwood JR. Recognition of vertebral fracture in a clinical setting. Osteoporos Int J 2000;11:577-82.
25. Kim N, Rowe BH, Raymond G, Jen H, Colman I, Jackson SA, *et al*. Underreporting of vertebral fractures on routine chest radiography. AJR Am J Roentgenol 2004;182:297-300.
26. Majumdar SR, Kim N, Colman I, Chahal AM, Raymond G, Jen H, *et al*. Incidental vertebral fractures discovered with chest radiography in the emergency department: Prevalence, recognition, and osteoporosis management in a cohort of elderly patients. Arch Intern Med 2005;165:905-9.
27. 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 2005;20:557-63.
28. Link TM, Guglielmi G, van Kuijk C, Adams JE. Radiologic assessment of osteoporotic vertebral fractures: Diagnostic and prognostic implications. Eur Radiol 2005;15:1521-32.
29. Lenchik L, Rogers LF, Delmas PD, Genant HK. Diagnosis of osteoporotic vertebral fractures: Importance of recognition and description by radiologists. AJR Am J Roentgenol 2004;183:949-58.
30. Smith RW Jr, Eyler WR, Mellinger RC. On the incidence of senile osteoporosis. Ann Intern Med 1960;52:773-81.
31. Barnett E, Nordin BE. The radiological diagnosis of osteoporosis: A new approach. Clin Radiol 1960;11:166-74.
32. Kleerekoper M, Nelson DA. Vertebral fracture or vertebral deformity. Calcif Tissue Int 1992;50:5-6.
33. Hurxthal LM. Measurement of anterior vertebral compressions and biconcave vertebrae. AJR Am J Roentgenol 1968;103:635-44.
34. Diacinti D, Guglielmi G. Vertebral morphometry. Radiol Clin North Am 2010;48:561-75.
35. Jergas M, San Valentin R. Techniques for the assessment of vertebral dimensions in quantitative morphometry. In: Genant HK, Jergas M, van Juijk C, editors. Vertebral fracture in osteoporosis. San Francisco (CA): University of California Osteoporosis Research Group; 1995. p. 163-88.
36. Genant HK, Wu CY, van Kuijk C, Nevitt MC. Vertebral fracture assessment using a semiquantitative technique. J Bone Miner Res 1993;8:1137-48.
37. Gehlbach SH, Bigelow C, Heimisdottir M, May S, Walker M, Kirkwood JR. Recognition of vertebral fracture in a clinical setting. Osteoporos Int J 2000;11:577-82.
38. Jensen GF, McNair P, Boesen J, Hegedüs V. Validity in diagnosing osteoporosis. Observer variation in interpreting spinal radiographs. Eur J Radiol 1984;4:1-3.
39. Genant HK, Jergas M, Palermo L, Nevitt M, Valentin RS, Black D, *et al*. Comparison of semiquantitative visual and quantitative morphometric assessment of prevalent and incident vertebral fractures in osteoporosis. The Study of Osteoporotic Fractures Research Group. J Bone Miner Res 1996;11:984-96.
40. Wu CY, Li J, Jergas M, Genant HK. Comparison of semiquantitative and quantitative techniques for the assessment of prevalent and incident vertebral fractures. Osteoporos Int J 1995;5:354-70.
41. Li J, Wu CY, Jergas M, Genant HK. Diagnosing prevalent vertebral fractures: A comparison between quantitative morphometry and standardized visual (semiquantitative) approach. In: Genant HK, Jergas M, van Kuijk C, editors. Vertebral fracture in osteoporosis. University of California, San Francisco, CA: Radiology Research and Education Foundation; 1995. p. 271R-9.
42. Spector TD, McCloskey EV, Doyle DV, Kanis JA. Prevalence of vertebral fracture in women and the relationship with bone density and symptoms: The Chingford Study. J Bone Miner Res 1993;8:817-22.
43. Black DM, Palermo L, Nevitt MC, Genant HK, Epstein R, San Valentin R, *et al*. Comparison of methods for defining prevalent vertebral deformities: The Study of Osteoporotic Fractures. J Bone Miner Res 1995;10:890-902.
44. Guglielmi G, Muscarella S, Leone A, Peh WC. Imaging of metabolic bone diseases. Radiol Clin North Am 2008;46:735-54.
45. Ferrar L, Jiang G, Adams J, Eastell R. Identification of vertebral fractures: An update. Osteoporos Int J 2005;16:717-28.
46. Ferrar L, Jiang G, Schousboe JT, DeBold CR, Eastell R. Algorithm-based qualitative and semiquantitative identification of prevalent vertebral fracture: Agreement between different readers, imaging modalities, and diagnostic approaches. J Bone Miner Res 2008;23:417-24.
47. Müller D, Bauer JS, Zeile M, Rummeny EJ, Link TM. Significance of sagittal reformations in routine thoracic and abdominal multislice CT studies for detecting osteoporotic fractures and other spine abnormalities. Eur Radiol 2008;18:1696-702.
48. Williams AL, Al-Busaidi A, Sparrow PJ, Adams JE, Whitehouse RW. Under-reporting of osteoporotic vertebral fractures on computed tomography. Eur J Radiol 2009;69:179-83.
49. Maldague BE, Noel HM, Malghem JJ. The intravertebral vacuum cleft: A sign of ischemic vertebral collapse. Radiology 1978;129:23-9.
50. Samelson EJ, Christiansen BA, Demissie S, Broe KE, Zhou Y, Meng CA, *et al*. Reliability of vertebral fracture assessment using multidetector CT lateral scout views: The Framingham Osteoporosis Study. Osteoporos Int J 2011;22:1123-31.
51. Bauer JS, Link TM. Advances in osteoporosis imaging. Eur J Radiol 2009;71:440-9.
52. Link TM. Osteoporosis imaging: State of the art and advanced imaging. Radiology 2012;263:3-17.
53. Guglielmi G, di Chio F, Vergini MR, La Porta M, Nasuto M, Di Primio LA. Early diagnosis of vertebral fractures. Clin Cases Miner Bone Metab 2013;10:15-8.
54. Malghem J, Maldague B, Labaisse MA, Dooms G, Duprez T, Devogelaer JP, *et al*. Intravertebral vacuum cleft: Changes in content after supine positioning. Radiology 1993;187:483-7.
55. Uetani M, Hashmi R, Hayashi K. Malignant and benign compression fractures: Differentiation and diagnostic pitfalls on MRI. Clin Radiol 2004;59:124-31.
56. Tehranzadeh J, Tao C. Advances in MR imaging of vertebral collapse. Semin Ultrasound CT MR 2004;25:440-60.
57. Griffith JF, Yeung DK, Antonio GE, Lee FK, Hong AW, Wong SY, *et al*. Vertebral bone mineral density, marrow perfusion, and fat content in healthy men and men with osteoporosis: Dynamic contrast-enhanced MR imaging and MR spectroscopy. Radiology 2005;236:945-51.
58. Griffith JF, Yeung DK, Antonio GE, Wong SY, Kwok TC, Woo J, *et al*. Vertebral marrow fat content and diffusion and perfusion indexes in women with varying bone density: MR evaluation. Radiology 2006;241:831-8.
59. Griffith JF, Yeung DK, Tsang PH, Choi KC, Kwok TC, Ahuja AT, *et al*. Compromised bone marrow perfusion in osteoporosis. J Bone Miner Res 2008;23:1068-75.
60. Tang GY, Lv ZW, Tang RB, Liu Y, Peng YF, Li W, *et al*. Evaluation of MR spectroscopy and diffusion-weighted MRI in detecting bone marrow changes in postmenopausal women with osteoporosis. Clin Radiol 2010;65:377-81.
61. Ferrar L, Jiang G, Eastell R, Peel NF. Visual identification of vertebral

fractures in osteoporosis using morphometric X-ray absorptiometry. J Bone Miner Res 2003;18:933-8.
62. Felsenberg D, Gowin W, Diessel E, Armbrust S, Mews J. Recent developments in DXA. Quality of new DXA/MXA-devices for densitometry and morphometry. Eur J Radiol 1995;20:179-84.
63. Steiger P, Cummings SR, Genant HK, Weiss H. Morphometric X-ray absorptiometry of the spine: correlation *in vivo* with morphometric radiography. Study of Osteoporotic Fractures Research Group. Osteoporos Int J 1994;4:238-44.
64. Lewiecki EM, Laster AJ. Clinical applications of vertebral fracture assessment by dual-energy X-ray absorptiometry. J Clin Endocrinol Metab 2006;91:4215-22.
65. Vogt TM, Ross PD, Palermo L, Musliner T, Genant HK, Black D, *et al*. Vertebral fracture prevalence among women screened for the Fracture Intervention Trial and a simple clinical tool to screen for undiagnosed vertebral fractures. Fracture Intervention Trial Research Group. Mayo Clin Proc 2000;75:888-96.
66. Cho WI, Chang UK. Comparison of MR imaging and FDG-PET/CT in the differential diagnosis of benign and malignant vertebral compression fractures. J Neurosurg Spine 2011;14:177-83.
67. Kato K, Aoki J, Endo K. Utility of FDG-PET in differential diagnosis of benign and malignant fractures in acute to subacute phase. Ann Nucl Med 2003;17:41-6.
68. Bredella MA, Essary B, Torriani M, Ouellette HA, Palmer WE. Use of FDG-PET in differentiating benign from malignant compression fractures. Skeletal Radiol 2008;37:405-13.
69. Elgazzar AH, Kazem N. Metastatic bone disease: Evaluation by functional imaging in correlation with morphologic modalities. Gulf J Oncolog 2009;5:9-21.

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