**Evaluating the Diagnostic and Clinical Value of Lumbar Spine CT: A Systematic Review**

# ABSTRACT

Aims: To determine whether there are significant findings in CT lumbar spine imaging to justify the radiation dose delivered to organs and tissues in the abdominopelvic region and assess clinical validation for using alternatives such as plain film imaging or magnetic resonance imaging.

Study Design: The study is a systematic review. Various published studies from PUBMED, MEDLINE, CINAHL and APA Psych INFO were used to gather data. A literature search was conducted using 4 reputable databases from the past years (2018 to 2022). Appraisal of the papers was conducted using the relevant CASP criteria to justify and validate the quality of the papers. 3 key themes emerged from the data and were prominent in the literature; they became the main foci.

Results: Fracture, osteoporosis, and bone mineral density (BMD) are findings that are interlinked and related to diseases of the lumbar spine, and CT was performed to identify them. Undetected lumbar spine fractures were apparent in the majority of osteoporotic patients; however, not all patients have been diagnosed with them. Using the information gathered from this review, checklists have been created to highlight criteria for diagnosing lumbar spine fractures, determining osteoporosis or in the assessment of bone mineral density. Guidelines must be adhered to before referring patients for CT imaging (or alternative imaging modalities such as X-ray, MRI or DXA). Patients need to be made aware of potential side effects and shortcomings of these investigations.

Conclusion: CT lumbar spine imaging still has a huge role to play in routine clinical practice, particularly in the detection of fractures. In the future, adequate information and support could be offered to referring doctors and physicians for diagnosing lumbar spine abnormalities.

***Keywords:*** *Lumbar spine, CT imaging, Fractures, Osteoporosis, Bone mineral density (BMD), X-ray, MRI*

# INTRODUCTION

Given the prevalence of symptoms like low back pain in adults, the lumbar region of the vertebral column has been the subject of the most research on any spinal segment [1]. Wear has been observed to cause a wide range of common pathological abnormalities in this region, including spondylosis, spondylolisthesis, and fractures [2]. The lumbar region is being targeted for fractures involving other areas as well, such as sacral insufficiency fractures (SIF), because they are adjacent and cause pain in the lower back [3].

Lumbar malformations are widespread in sub-Saharan Africa, accounting for 30-40% of rheumatology visits [4]. Thomas [5] reiterates that damage to the vertebrae in the lumbar area demands rapid care and examination, as it has the potential to produce long-term neurological deficits by compressing or damaging the nerve roots in the spinal cord. The investigative techniques involve the use of imaging procedures, such as computed tomography (CT), magnetic resonance imaging (MRI), plain film imaging, nuclear medicine, dual-energy Xray densitometry (DXA) as well as non-imaging techniques consisting of cerebrospinal fluid (CSF) analysis and electrophysiological studies [6, 7].

Plain film imaging of the lumbar spine is the first line of investigation and can be done using Antero-posterior (AP) or Postero-anterior (PA) as well as lateral positions to examine lumbar bony alignment, disc space size, and soft tissue areas [4, 8]. According to Kim et al. [3], CT and MRI are the second-line imaging modalities, which also help in confirming diagnoses and determining the course of treatment. Although CT is extremely useful for confirming and ruling out alternative diagnoses, it has a high radiation dose and cannot detect certain spinal cord lesions, disc pathologies, and minor lesions. MRI, known as the gold standard, has superior imaging properties and high spatial resolution due to its multiple sequencing protocols.

MRI, unlike CT, is very safe for imaging reproductive organs because it does not contain radiation [9]. MRI has traditionally been regarded as the technique of choice for spinal neuroimaging and provides greater tissue detail [6]. Additionally, it has been shown to be especially sensitive in identifying a variety of degenerative changes and metastases in the spine, though those who underwent MRI for symptoms like low back pain experienced a longer duration of impairment and required surgery as a result [10]. Despite this, concerns about the risks of ionizing radiation are more focused on radiotherapy than on CT or general radiography [7].

CT has the potential to cause long-term health effects such as cancer if radiodiagnostic procedures are performed on a single patient over an extended period of time, particularly in female patients with reproductive organs near the lumbar spine, which are more vulnerable to ionizing radiation [11]. Following an initial review of cancelled CT requests at a specific NHS site, anecdotal evidence revealed that a number of CT scans were unnecessary. Given the radiation dose associated with CT imaging, it was questioned whether the majority of lumbar spine CT scans performed in current practice were truly needed. Since there has not been a comprehensive analysis of the literature determining the importance of lumbar CT spine imaging, this study fills that gap in current clinical practice. This study, therefore, highlights criteria and imaging modalities for diagnosing lumbar spine abnormalities following appropriate guidelines and adding to the existing literature database by discovering papers, justifying their methods, critiquing them, analyzing their results, and making recommendations that could be used in future studies.

# OBJECTIVES

This study aims to determine whether there are significant findings in CT lumbar spine imaging to justify the radiation dose delivered to organs and tissues in the abdominopelvic region. To also assess clinical validation for using alternatives such as plain film imaging or magnetic resonance imaging.

# METHODS

## Systematic Search

A systematic search was performed, with a focus on publications published within a five-year radius. Studies with patients from the age group of 18 to 80 years were the primary focus of this work and they included lumbar spine malformations of all types, such as spondylosis, spondylolisthesis, fractures, vertebral instability, etc.

A formal strategy for searching databases on the role of CT in lumbar spine imaging, associated findings and diagnostic relevance in current practice was needed to gather extensive papers to assist in formulating the research question. To cover practically all published articles in tropical medicine and health-related topics, we made use of databases relevant to the research topic; hence, four well-known electronic scientific databases were assessed: Medline, PubMed, CINAHL and APA Psych INFO. Eriksen and Frandsen [12] also proposed using the PICO (Population, Intervention, Comparator, Outcome) framework to direct the examiner to select a specific key term for the search, which aids in locating the problem, intervention, and outcome associated with a specific type of care provided to the patient (table 1).

Boolean operators were used to broaden sets of results and provide those that are most relevant to the research topic and citation. Pearl search was used to discover additional sources of information using a subject term. All searches were recorded using a spreadsheet to ensure transparency. The search terms developed include ‘lumbar spine CT imaging findings,’ ‘radiation dose in lumbar spine CT', and ‘clinical justification of lumbar spine CT.’ table. 2 contains synonyms that were developed to guarantee the inclusivity of every pertinent study. December 2021–December 2022 was the timeframe for performing the search. The author examined the titles, dates, and abstracts to select papers that met the criteria. The PRISMA flowchart was also utilized to illustrate the search procedure in order to enhance the critical review's reporting (Fig. 1).

**Table 1: The PICO framework used to aid in the formulation of the search strategy**



**Table 2: A table containing the major aspects of the study topic**



**Figure 1: PRISMA Flowchart demonstrating the data selection process**



## Inclusion Criteria and Exclusion Criteria

To prevent selection bias from tainting the results of this research, strict inclusion criteria were established for the participants. According to Jahan & Naveed [13], setting out a clear and rigorous criterion for inclusion prior to starting the search process is a strategy for limiting selection bias.

Studies involving paediatric patients would not be included because they do not fit the proposed work's timeframe and framework. According to Dowdell et al. [14], paediatric patients and their injury patterns are diverse and distinct from those of adults and may take time to gather for the timeframe of this project. Scoliotic patients were also excluded from the list of studies. Jarrett & Ecklund [15] reiterated that vertebral morphology is difficult to accurately characterise in scoliotic patients due to the curvature of the spine; hence, it may taint the findings. Post-mortem studies will be excluded as well. It has been discovered that autopsy surpasses imaging in post-mortem studies, and even if imaging is done, they are mostly for cardiac-related death [16].

Studies with patients who are morbidly obese are exempted as well. Woods & Sloan [17] stipulate that optimal image quality for the assessment of lumbar spine malformations is based on factors such as adequate exposure and proper positioning, which can be difficult when the patient is obese, increasing the likelihood of false positives. Studies with patients who have metallic instrumentation in situ were also excluded due to the impact of artefacts on image quality. Metal implants degrade image quality and increase radiation exposure which have been observed in patients with hip implants [18].

To give a wider variety of publications for evaluation, no restrictions were placed on the kinds of methods to be included in the literature review, which is a limitation of this research. However, doing so creates a big difficulty in terms of combining and comparing diverse methodologies. Notwithstanding, a vigorous and transparent review procedure in accordance with PRISMA criteria was used to increase reproducibility (Appendix 1). Only publications vetted and approved by experts in the field were considered for inclusion to guarantee the maximum degree of credibility for the results.

## Data Extraction and Synthesis

Possibly eligible studies were examined meticulously, and common themes were identified. Three key themes emerged from the data and were prominent in the literature; they became the main foci. Appraisal of the papers was conducted using the relevant Critical Appraisal Skills Programme (CASP) criteria; these were done to justify and validate their quality.

After reviewing each publication, the papers were appraised using the relevant CASP criteria (Appendix 2). Long et al. [19] highlight that the CASP tool helps in validating and justifying the quality of the papers so that the information they portray can be relied upon. To prevent data loss and explain the critical review procedure, the researcher retained physical copies of all articles and CASP checklists (Appendix 2) that accompanied them. The information gathered from each article was collated into a table (Appendix 2) that included participant numbers, methodology, results, conclusions, and findings.

This is a broad synopsis of each of the listed studies. 54 papers were eligible, but 14 papers were the most relevant and strongest sources that expressed the three themes; the remaining research was disregarded because of reasons such as wrong population, etc.

# RESULT

This section will critically evaluate the studies in this area that emphasize the findings in CT lumbar spine imaging. Three recurring themes were prominent in the data and literature search. Fracture, bone mineral density (BMD), and osteoporosis.

## Fracture

The occurrence of fracture was a dominant theme identified in the data. The research of Sollmann et al. [20] sought to examine whether CT/MRI evidence could be used in distinguishing patients with and without fractures due to osteoporosis and if it can be used to predict volumetric bone mineral density (vBMD). This study analysed CT and MRI scan data of 26 patients; the modest population number limited this work, which the authors admitted to, and thus the findings of this study are largely illustrative of this group of patients. Texture features from CT and the chemical shift encoded (CSE) MRI protocol were utilised for this study, and the main anatomic target was the thoracic and lumbar spine. Data from CT was used to segment 171 vertebrae of the thoracolumbar spine using a framework called a convolutional neural network, a network station that helps in labelling/annotating vertebral bodies and converting CT Hounsfield unit (HU) to vBMD.

For MRI, a chemical shift-encoded protocol was performed, followed by a T2\* protocol. The authors used stepwise multivariate linear regression models to determine the relationship between the dependent variable (fractured group) and the independent variable. In their results, CT imaging revealed 11 patients (42%) with osteoporotic vertebral fractures. These patients (with fractures) had poor vBMD as compared to those without. In addition, Sollmann et al. [20] highlighted that, for distinguishing patients with and without fractures due to osteoporosis, incorporating textural characteristics from two modalities (CT, MRI) performed better than one based on vBMD from one imaging tool. The explanation for this result from the regression model was that vBMD and more than one texture feature (from CT and MRI) explained about 81% of the variation concerning fractures in patients with osteoporosis of the spine, as opposed to 47% when grounded on a single texture feature from MRI alone. The authors did not investigate whether a single texture feature from CT alone performed better as opposed to CT/MRI combined, which limited this study. Also, fracture detection was only performed with the CT modality; no reference was made to MRI. The authors hypothesised that individuals with vertebral fractures caused by osteoporosis had substantially reduced BMD as opposed to patients without fractures. The conclusion is that the extrapolation of fractures in patients with osteoporosis can be improved by using texture analysis for both MRI and CT of the spine. This may help differentiate osteoporotic patients, regardless of whether they have spinal fractures or not.

Allaire et al. [21] also conducted a case-control study using CT finite element analysis (FEA) to predict incident spinal fractures. The authors sought to determine if a correlation could be established between lumbar vertebral strength and fracture propensity and also draw some parallels between BMD and FEA. They defined an incident vertebral fracture as a fracture in a previously identified vertebra or a new fracture in a previously fractured vertebra. In this study, 26 individuals with fractures and 62 controls between the age range of 50 and 80 years old were identified from the CT database of a local hospital in Framingham, Massachusetts. As with Sollmann et al. [20], the small number of participants used was a substantial limitation. The data obtained from the lumbar spine CT scan was used to study the lumbar compressive strength and measure volumetric/areal bone mineral density (vBMD/aBMD) against the controls. Sollmann et al. [20] stated that while aBMD represents the area measurement of BMD, vBMD represents the volume. For each case, 2 to 4 age- and sex-matched controls that had no fracture were used to compare against those that had fractures. As opposed to the linear regression model in [20], the authors in this study used the receiver operating characteristic (ROC) curve and area under the curve (AUC) to establish the relationship between vertebral strength and incident vertebral fracture. In their findings, patients with spinal fractures had reduced BMD. It was also discovered that the compressive strength of the lumbar spine was significantly linked to an elevated possibility of a recent or deteriorating vertebral fracture. The researchers declared that CT FEA had higher sensitivity for diagnosing vertebral fracture and frail bone strength as opposed to aBMD but not better than vBMD. Allaire et al. [21] concluded that there was a strong relationship between vertebral strength and incident vertebral fracture. They suggested that CT FEA of bony strength offers comparable or superior incident vertebral fracture predictability potential as compared to CT areal or vBMD.

A few other authors have advised for CT to be used to screen patients for vertebral fractures when they present for other investigations such as oncological abdominal scans (opportunistic CT scan), but, unfortunately, the list of examinations that could be used for this purpose remains unclear [22. 23]. Fracture prediction via DXA BMD assessment has been acclaimed as the gold standard by WHO; although linked with some setbacks, Leonhardt et al. [23] sought to determine if BMD evaluated with CT when patients present for other reasons can predict fracture and how this compares to DXA. This research was a prospective 3-year follow-up study with 58t individuals over the age of 60 who were hospitalised with fractures. The prospective nature of this research added credibility and enhanced the significance of the results and possible implications for this field of medicine. The patients recruited for this study had varying degrees of fractures located at different parts of the body and on the lumbar spine as well. The inclusion criteria for this study were that patients must have undergone a CT scan for a suspected lumbar vertebral fracture. All patients had baseline CT, but only 31 patients had baseline DXA. As with Sollmann et al. [20], the CT scanner software was used to convert HU on the sagittal reformatted images to vBMD. BMD measurement from DXA (areal BMD) was performed as well (values in T-score). The method for obtaining the HU in this research was performed manually in contrast to Sollmann et al. study. A region of interest (ROI) measuring instrument was put on the sagittal CT image, which provided the HU values. As opposed to Sollmann et al. [20], but in agreement with Allaire et al. [21], the authors in this study used ROC and AUC to assess patients with and without new fractures. Leonhardt et al. [23] results brought light to the fact that 34% of the patients enrolled during the 3-year timeframe had new fractures on CT, the majority due to osteoporosis (not far from Sollmann et al. 42% finding). When BMD from DXA was compared to BMD from CT, the DXA T-score did not differ between patients with and without fractures, and DXA struggled to diagnose patients with osteoporosis. CT, on the other hand, revealed fractures while also distinguishing between patients with low and high BMD and identifying osteoporotic patients. In addition, the BMD of patients with fractures on CT was lower than that of those without fractures but on DXA, the BMD in the fracture vs non-fracture group did not differ significantly. Leonhardt et al. [23] concluded that opportunistic BMD assessments accomplished with CT imaging forecasted fractures during this follow-up study, which indicates that opportunistic measurements will assess the probability of possible fractures in osteoporotic patients.

Löffler et al. [22] also made a comparison between opportunistic CT BMD assessment vs DXA and their diagnostic performance in the detection of incident vertebral fractures. In contrast to Leonhardt et al. [23], this study was a retrospective observational study that involved 84 osteoporotic patients (above 50 years) who underwent baseline CT scans and follow-up in 12 months. Since only osteoporotic patients were used for this study, selection bias was introduced, which the authors agreed to; they stipulated that this was the case as osteoporosis was already highlighted due to joint CT and DXA imaging performed. Hence this study, for future research, will apply to osteoporotic cohorts. In conjunction with Leonhardt et al. [23], sagittal reformatted images were used to determine HU values for BMD calculation. DXA was performed on all the patients for this study; the T-score of the lumbar spine, proximal femur and both hips were used for this assessment. Results revealed that CT detected new fractures in 16 of the 84 osteoporotic patients (19%). Their results agreed with Leonhardt et al. [23] findings on different grounds: first, CT had higher accuracy at detecting osteoporosis as opposed to DXA (81% CT as opposed to 44% DXA); secondly, there was a negligible difference in the DXA T-score in patients with fractures vs those without fractures; and thirdly, CT BMD had higher accuracy in discriminating between patients with/without incident fractures to the vertebrae. These findings provide valuable insight into the works of Leonhardt et al. that stated that DXA BMD accounts for a minimal variation in bone mineral content and strength. Löffler et al. [22] stated that the probability of incident vertebral fractures being detected by CT BMD was good (agreed by Allaire et al. [21]) but was not significant by DXA BMD T scores. They reached the same conclusion as Leonhardt et al. [23] that screening patients in CT opportunistically allows for better risk assessment of forthcoming fractures of the vertebrae than dedicated DXA.

## Bone Mineral Density (BMD)

According to Löffler et al. [22], BMD has been established as a tool for assessing fracture risk. Perrier-Cornet et al. [24] reveal that a major consequence of decreased BMD is fracture. Common sites for measuring the BMD are the lumbar spine, thoracic spine, and hip/femoral neck. According to WHO guidelines, a DXA T-score of -1.0 and above indicates normal BMD, whereas a result of -1.0 to -2.5 and lower suggests an anomaly that represents osteopenia or osteoporosis.

Cohen et al. [25] conducted a retrospective study to investigate tolerance levels for CT HU used opportunistically to detect abnormal or aberrant BMD and distinguish osteoporotic from non-osteoporotic patients. 64 years old was the mean age of participants. They underwent lumbar spine CT or CT of the abdomen (for other purposes) and DXA in a timeframe of six months (as opposed to a 12-month study by Löffler et al.). Sagittal reformatted images were used to examine the vertebral bodies for fractures before performing HU measurement on the axials. BMD measurements from DXA were performed, and CT lumbar spine HU was compared to the BMD from DXA hip/lumbar spine. Of the 246 patients utilised for this study, 83% had abnormal bone mineral density on DXA 27% osteoporosis, 56% osteopenia) while only 17% were found to have normal BMD. Patients with fractures on CT were 44% (28% with pre-existing osteoporosis and osteopenia while 5% had normal BMD). Older patients were mainly afflicted by osteoporosis and osteopenia. The thresholds for the CT HU were as follows (table 3). In this study, patients with aberrant BMD had a lower T-score (-3.05 to -1.8) on DXA than those with normal BMD (-0.25). The authors stated that higher age was associated with abnormal BMD on DXA and CT scans. They hypothesised that their findings demonstrate a significant association between DXA and CT HU BMD assessment (p<0.001), concluding that there was a significant link between HU measurements on lumbar spine CT and DXA BMD. Similar to Sollmann et al. [20] and Allaire et al. [21], the retrospective nature of this research was a weakness of the study.

**Table 3: CT HU and threshold levels (Cohen et al., 2021)**



Gruenewald et al. [26] study sought to establish whether phantomless dual-source, dual-energy CT (DECT) BMD evaluation could predict a 24-month risk of developing osteoporotic-related fracture. In this research, the first lumbar vertebrae were evaluated retrospectively in 92 individuals (mean age 64). Patients were considered for this investigation if they had an L1 vertebral fracture caused by osteoporosis. Dual-energy CT software manipulation of material decomposition was utilised for phantomless BMD evaluation.The material decomposition process involved the manipulation of tissue density at different energy levels, enabling precise boundaries between bone and soft tissues. CT HU was determined by a radiology resident in all patients utilised for this study. The trabecular aspect of the L1 vertebra was the central focus for this study as per CT-HU determination. Using ROC and logistic regression analysis, the researchers examined the relationship between BMD, gender, age and how these factors influence the risk/presence of osteoporotic fractures. Their findings indicated that DECT BMD had 85.45% sensitivity and 89.19% specificity for forecasting recent fractures in osteoporotic patients within 24 months after bone mineral density investigation. This study demonstrates that CT, whether dual or single source, is an effective tool for identifying fractures and measuring BMD/osteoporosis, although the authors failed to employ DXA as a comparative variable, which has been utilised in prior investigations. The researchers revealed that an increased BMD indicated a safe bone condition and concluded that BMD assessment analysed retrospectively with DECT can forecast the two-year chance of sustaining a fracture due to osteoporosis in patients with predisposing factors without a phantom. Furthermore, lower BMD estimates are greatly linked with a heightened chance to suffer from fragility fractures. As the authors point out, patients who had CT did so because X-rays failed to adequately diagnose fractures; hence, this research was flawed by a preselection bias. The research also had the flaw of not distinguishing between patients with and without contrast, nor the variability in the amount and flow rate of contrast given, which might have affected the results; hence, it is uncertain if BMD examination of the lumbar spine can be performed during portal venous phase abdominal imaging and if this has the same diagnostic confidence as that of non-enhanced imaging.

In a rare article employing MRI, Kale & Yadav [27] looked at the relationship between BMD and the risk of fracture by testing the hypothesis that the T1 signal of the lumbar spine/CSF on MRI may better predict lower density of the bone. This investigation was retrospective, involving 36 patients (45 to 73 years) that underwent lumbar spine MRI and dual-energy X-ray absorptiometry scans as part of a yearly health examination. The method for analysing the T1 signal of the vertebral bodies contrasted with the CT-HU assessment in previous studies [25, 28]; here, a radiologist used a measurement calliper to acquire the signal intensity (SI) of the entire lumbar (L1-L4) VB volume. The same procedure was carried out for assessing the SI of the CSF but using a much smaller width. The authors provided no explanation why the measurement was conducted in this manner, which would have bolstered this study, probably because the whole anatomic area represented the signal strength. A DXA scan was done as well; the radiologist who performed the SI computations was not informed of this additional investigation. As in previous research [20, 21], regression analysis, pearson correlation and odds ratio were employed to establish the connection between BMD and signal intensity. Their results revealed that there was a weakly negative relationship between the vertebral body of T1 and the T1 cerebrospinal fluid signal intensity ratio and bone mineral density; hence, a high signal of T1 (vertebral body/cerebrospinal fluid ratio) on routine lumbar spine MRI protocol signals diminished BMD. This research addresses a gap in Sollmann et al. [20] work and is vital for establishing MRI as a potentially useful tool for measuring BMD and forecasting fractures. This may also aid in reducing the number of osteoporotic fractures seen in emergency rooms.

## Osteoporosis

A recurrent theme identified as a precursor of vertebral fracture by Cohen et al. [25] was osteoporosis, which has been denoted by Löffler et al. [22] as a disease that affects a substantial proportion of the population. Hendrickson et al. [29] emphasised that osteoporosis is equivalent to a condition of diminished BMD, linked with a high likelihood of futuristic fracture. Li et al. [28] and Hendrickson et al. [29] stated that osteoporosis is assessed based on factors such as CT HU, BMD, and T-scores from DXA.

Li et al. [28] study analysed the likelihood of detecting osteoporosis in CT for non-spine investigations (opportunistic) in a population of Chinese patients. The patients for this study had two screening investigations, DXA and CT, within a six-month period that were utilised. It is worth mentioning that this method of recruiting participants is a recurring pattern performed in other works [25] for the assessment of osteoporosis and abnormal BMD. In this study, the medical records of 109 individuals (ranging in age from 51 to 75 years) were examined retrospectively. Similar to Gruenewald et al. [26], Li et al. relied on radiologists to interpret scans for osteoporosis and detect fractures. Sagittal reconstructed images were used for the ROI placement for determining HU. The HU derived from the lumbar vertebrae on CT were correlated statistically with measurement values on DXA. ROC graphs and assessment curves were used to prove the threshold cut-off values, sensitivity and specificity. In their results, the diagnosis of osteoporosis was established at HU of less than 97 osteopenia—HU between 97 and 135, while normal individuals had HU above 230 (as opposed to Cohen et al.). The best threshold for ruling out osteoporosis or osteopenia was HU greater than or equal to 175 with 99% negative predictive value (NPV) (ROC of 0.97). The researchers revealed that a Pearson correlation of 0.62 and 0.61 indicated that a good relationship existed between the average HU on CT, BMD and DXA T-score values.

Studies regarding HU threshold levels for the assessment of BMD and diagnosis of osteoporosis have well been established for patients in the west [23]. Li et al.'s retrospective study is the first to establish similar thresholds for attenuation values of the lumbar vertebrae (L1-L5) within a Chinese cohort to aid in the implementation of an opportunistic CT imaging assessment program in Asia for the diagnosis of osteoporosis, although previous works did assert that race has no impact on CT HU levels. Li et al. [28] concluded that screening for osteoporosis could be detected early while reporting on CT scans of the abdomen, a trend that could improve prevention of fractures in osteoporotic patients. They recommended that when suspicions of osteoporosis are raised on CT imaging, DXA should be expedited to prevent fracture (consistent with Cohen et al. [25] findings), and HU figures that lean towards the osteoporotic divisions for patients without fracture may be a warning indicator for future fracture.

The osteoporosis retrospective cohort research of Hendrickson et al. [29] addressed a shortcoming of the Li et al. [28] study. The latter used solely elderly patients for their research. Whilst it has been demonstrated in prior research that older people are more afflicted by osteoporosis than younger ones, it is reasonable to assume that the findings of the study (if younger participants are recruited) might be applicable to a broader age range in future studies. Hendrickson et al. sought younger and older individuals to create reference values for lumbar spine CT HU and demonstrate the accuracy of DXA T-scores in identifying osteoporotic individuals. The participants for this study were 455 in total: 190 young participants (mean age 25 years) as the reference cohort and 256 elderly subjects (mean age 58 years) as the validation cohort. For this research, participants in the validation group had two diagnostic procedures, DXA and CT, 6 months apart (as in Li et al. (2018)), while those in the reference had one—CT. Osteoporosis was classified as ≤ -2.5 T-score on DXA according to the WHO criteria. The first to fourth lumbar vertebrae were utilised to generate the HU for the reference group; the same anatomical region was used to estimate the T-score in the validation cohort. There is a recurring trend of avoiding L5 for the calculation of the CT HU, but the reason for this has not been determined; it may be due to L5/S1 connectivity or other unknown causes. Hendrickson et al. measured the sensitivity/specificity of T-score and HU using ROC curves, which reinforced this study (same method in Li et al., 2018). In their results, the reference cohort (normal young individuals) HU ranged from 227 to 236 (± 42) at L3 and L1, respectively (confirming previous studies [25, 28]). The authors revealed which T-scores level equated to HU, not previously done by Cohen et al. [25]. They also established that a T-score of -3.0 was equivalent to 110 HU, while -2.5 was equivalent to 153 HU. The validation group T-score DXA was -0.7 and -0.9 ± 1.5 and 1.2 at lumbar and femoral sites, respectively. A 48% and 91% sensitivity and specificity were illustrative of osteoporosis at HU of –3.0 (110 HU) and –2.5 (153 HU) (opposed to Li et al., [28]). The ROC data was 0.825 to 0.853, the same range as the Li et al. study. Hendrickson et al. [28] arrived at a conclusion that patients with a lumbar T-score HU ≤ -3.0 ought to be referred for additional diagnostic procedures such as CT (supported by Cohen et al. [25]).

Of the literature assessed and evaluated, the first lumbar vertebrae have been the focus of the most osteoporosis-related studies. Perrier-Cornet et al. [24] stipulated that this is because the L1 vertebral body is the first most easily identified non-rib-bearing vertebra and is less affected by degenerative changes. Abbouchie et al. [30], in contrast, declared that L1 CT HU values match DXA measurements and have the same prognostic value for the diagnosis of osteoporosis. In the study by Abbouchie et al., the HU of the L1 vertebral body in the reference group was quantified and compared to the L1 vertebral body collected from DXA in the validation group. 407 patients (mean age 65 years) had dual imaging investigations (CT abdomen and DXA) (same as Hendrickson et al., 2018) over the course of twelve months. Extraction of the L1 CT HU was performed axially. The same was also done of the T-score L1 vertebral body on DXA. As in Hendrickson et al. [29] and Li et al. [28] research, the AUC, specificity, and sensitivity were measured. Unlike other authors, Abbouchie et al. calculated the odds ratio.

Norton et al. [31] theorised that the odds ratio is used to establish the probability of an outcome or event occurring. Abbouchie et al. [30] findings revealed that L1 CT HU values aligned with L1 DXA T-score (p<0.01) and AUC value of 0.64 for distinguishing the following variables: BMD, osteoporosis, and osteopenia. HU of less than 180 (women) or less than 190 (overall) signalled an increased chance of osteoporosis in participants of Australian origin (not far from Hendrickson et al. [29] and Cohen et al. [25]) with an odds ratio of 4.4 to 4.7. This reinforces previous studies that race does not play a role in HU measurements. Of the patients used, about 12% had osteoporosis (none had fractures). The authors advised that in clinical practice, individuals above the threshold should undergo DXA (if not already done) to prevent fracture. However, one significant limitation of this study was that it was not possible to ascertain whether the patients used medications related to osteoporosis. Other authors did not suggest that this was a problem, so it is unclear whether this would have made a difference.

# DISCUSSION

The results from this critical review prove that in current practice there are substantial findings in CT lumbar spine imaging. From the research, it is evident that CT imaging aids in distinguishing between osteoporotic and non-osteoporotic vertebral fractures and also serves as a useful tool for estimating the bone mineral density, a test that predicts the likelihood of future fractures. Sollmann et al. [20] findings revealed that CT and MRI of the spine, when used together, are robust and perform better at spotting osteoporotic vertebral fractures or will perform better at predicting the risk of osteoporotic vertebral fracture than a medium based on BMD from a single imaging modality. Cohen et al. [25] proposed, however, that BMD assessment using CT HU measurement alone had a high likelihood of predicting fractures and identifying osteoporosis. This has been supported by Abbouchie et al. [30], suggesting that patients with a CT HU threshold below < 180 or < 190 signalled decreased BMD and are at high risk of osteoporosis and fracture; and only in this instance should a second diagnostic modality be performed to confirm the futuristic possibility of fracture.

Allaire et al. [21] conducted research to determine the likelihood or possibility of fracture in their case-control study on vertebral strength and finite element analysis. The uniqueness of this investigation pointed to the fact that CT data could reveal information on vertebral strength; the information from this was utilised to determine bone fragility and fracture tendency. According to Pizzato et al. [32], plain film imaging is still very helpful in detecting vertebral fractures. The fracture risk assessment tool utilised by Pizzato et al. [32] assisted in spotting fractures from thoracic/lumbar spine X-rays. Previous spinal X-ray imaging and recent plain film X-rays may in fact provide prompt detection and improved management and care for patients with fractures to the vertebral column without CT/MRI evidence.

Surprisingly, recent publications exalt CT for the evaluation of BMD. CT-derived BMD analysis with HU measurement has been proven to be reliable in predicting fracture [23, 24, 26], and this compares well with BMD estimations obtained by the better recognised gold standard—DXA (WHO). A high BMD implies healthy bones [26], while a low BMD denotes an anomaly [25]. The anomaly may be osteopenia or osteoporosis [32]. According to the collected literature, osteopenia is a precursor to osteoporosis [28]; it was not made clear why, maybe because patients with osteopenia are at risk of developing osteoporosis if they are not given proper treatment. WHO classifies osteoporosis as a DXA T-score of -2.5 and below, the CT threshold level for distinguishing patients with normal BMD and those with osteoporosis has been established by several authors in table 4 below.

**Table 4: Normal BMD vs Osteoporosis**



Hendrickson et al. [29] study was the only research that explicitly stated which T-scores level corresponds to a CT HU. They established that a T-score of -3.0 was equivalent to 110 HU, while -2.5 was equivalent to 153 HU (both cases represent osteoporosis). The HU is measured by positioning an ROI calliper tool centrally on the trabecular bone, away from the joints and interarticular facets. According to Cohen et al. [25], this area must first be analysed by a sagittal CT reformatted image to ensure that there are no fractures, spondylosis, or joint narrowing within the area, as these conditions can alter the values obtained.

A high T1 signal of the lumbar spine on MRI is suggestive of decreased bone density, according to Kale & Yadav [27], raising questions about whether MRI might provide insight into bone health. However, this research can only be applied to this patient cohort because it was limited by a very small and younger population. Many authors have demonstrated that the majority of bone malformations are found in older patients. Cohen et al.'s [25] findings supported that patients with abnormalities like osteoporosis, osteopenia, and fractures were older than those with normal bone mineral density.

## Recommendations

CT imaging is still linked with considerable findings that have been acknowledged in the literature. The exact impact of osteoporosis medication and contrast administration volume/flow rate on BMD assessment is unclear. Studies indicate that older patients are at a higher risk of ailments than younger patients; however, it would be incorrect to assume that all elderly people will have osteoporosis or abnormal BMD. Although the prevalence of vertebral fracture was reported in the majority of the research [21], not all patients had new incident fractures on CT imaging [22]. It would be advantageous to do a quantitative study on patients with new fractures to see how this discovery is being monitored over time and the effect it would have on their treatment pathway. Future studies must investigate how often BMD measurement is performed in CT departments to understand the impact of these investigations on current workload. The majority of the research interpreted their results as CT HU matching DXA T-score values. For instance, Hendrickson et al. [29] and Abbouchie et al. [30] discovered a correlation between L1 CT HU values and L1 DXA T-score; however, the methodology of DXA measurements was not clear, which needs to be clarified in subsequent studies. In addition, a large-scale comparative research of CT HU levels vs DXA T-score would assist in determining whether CT is a trustworthy tool for measuring BMD. In the great majority of studies, the patients recruited were already diagnosed with osteoporosis, introducing selection bias; it would be more beneficial for future research to include a diversity of patients with varying diagnoses. Based on the publications assessed, a checklist has been created (table 5) to act as a guideline for medical and healthcare professionals when referring patients for radiology investigation of the lumbar spine.

**Table 5: Guideline for Radiology investigation of the lumbar spine**



Uncertainty exists as to whether the NHS budget and current resources might cover the cost of these radiologic examinations; more funding from the government and non-governmental organisations would help to strengthen this.

# CONCLUSION

CT lumbar spine imaging still has a huge role to play in routine clinical practice, particularly in the detection of fractures. Guidelines must be adhered to before referring patients for CT imaging or alternative imaging modalities such as X-ray, MRI or DXA. The information gathered from this study can be used to create a catalogue designed to emphasize criteria for diagnosing fractures, osteoporosis, assessing bone mineral density, and, in the future, providing adequate information and support to referring doctors and physicians. .

**CONSENT AND ETHICAL APPROVAL**

It is not applicable.

**COMPETING INTERESTS**

Authors have declared that no competing interests exist.

# REFERENCES

1. Heary RF. Revision lumbar spine surgery. 1st ed. Elsevier, Inc.; 2022.
2. Aoki Y, Takahashi H, Nakajima A, Kubota G, Watanabe A, Nakajima T, et al. Prevalence of lumbar spondylolysis and spondylolisthesis in patients with degenerative spinal disease. Sci Rep. 2020. https://doi.org/10.1038/s41598-020-63784-0
3. Kim YY, Chung BM, Kim WT. Lumbar spine MRI versus non-lumbar imaging modalities in the diagnosis of sacral insufficiency fracture: A retrospective observational study. BMC Musculoskelet Disord. 2018. https://doi.org/10.1186/s12891-018-2189-1
4. Tannor AY. Lumbar spine X-ray as a standard investigation for all low back pain in Ghana: Is it evidence based? Ghana Med J. 2017;51(1):24–9. https://doi.org/10.4314/gmj.v51i1.5
5. Thomas RJF. Thoracolumbar spine fracture. StatPearls. Orlando: de Jesus; 2021.
6. Ricciardi M, Campanella A, Grieco G, Zammit R. Usefulness of spinal unenhanced computed tomography and CT-myelography in the age of multidetector CT technology and magnetic resonance imaging—preliminary considerations. Open Vet J. 2018. https://doi.org/10.4314/ovj.v8i3.6
7. Balasubramanya R, Selvarajan SK. Lumbar spine imaging. In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing; 2022. PMID: 31985974.
8. Alukic E, Skrk D, Mekis N. Comparison of anteroposterior and posteroanterior projection in lumbar spine radiography. Radiol Oncol. 2018;52(4):468–74. https://doi.org/10.2478/raon-2018-0021
9. Lee SH, Yun SJ, Jo HH, Song JG. Diagnosis of lumbar spinal fractures in emergency department: Low-dose versus standard-dose CT using model-based iterative reconstruction. Clin Imaging. 2018. https://doi.org/10.1016/j.clinimag.2018.04.007
10. Koch V, Albrecht MH, Gruenewald LD, Yel I, Eichler K, Gruber-Rouh T, et al. Impact of intravenously injected contrast agent on bone mineral density measurement in dual-source dual-energy CT. Acad Radiol. 2022. https://doi.org/10.1016/j.acra.2021.06.010
11. Skrzypek M, Wdowiak A, Panasiuk L, Stec M, Szczygieł K, Zybała M, et al. Effect of ionizing radiation on the female reproductive system. Ann Agric Environ Med. 2019. https://doi.org/10.26444/aaem/112837
12. Eriksen MB, Frandsen TF. The impact of patient, intervention, comparison, outcome (PICO) as a search strategy tool on literature search quality: A systematic review. J Med Libr Assoc. 2018;106(4):420–31. https://doi.org/10.5195/jmla.2018.345
13. Jahan N, Naveed S, Zeshan M, Tahir M. How to conduct a systematic literature review: A narrative literature review. Cureus. 2016;8(11):e864. https://doi.org/10.7759/cureus.864
14. Dowdell J, Mikhail C, Robinson J, Allen A. Anatomy of the paediatric spine and spine injuries in young athletes. Ann Joint. 2018. https://doi.org/10.21037/aoj.2018.03.01
15. Jarrett DY, Ecklund K. EOS imaging of scoliosis, leg length discrepancy and alignment. Semin Roentgenol. 2021. https://doi.org/10.1053/j.ro.2021.06.001
16. Michaud K, Genet P, Sabatasso S, Grabherr S. Postmortem imaging as a complementary tool for the investigation of cardiac death. Forensic Sci Res. 2019. https://doi.org/10.1080/20961790.2019.1630944
17. Woods AL, Miller PK, Sloane C. Patient obesity and the practical experience of the plain radiography professional: On everyday ethics, patient positioning and infelicitous equipment. Radiography. 2016. https://doi.org/10.1016/j.radi.2015.09.005
18. Song OK, Chung YE, Seo N, Baek SE, Choi JY, Park MS, et al. Metal implants influence CT scan parameters leading to increased local radiation exposure: A proposal for correction techniques. PLoS One. 2019. https://doi.org/10.1371/journal.pone.0221692
19. Long HA, French DP, Brooks JM. Optimising the value of the critical appraisal skills programme (CASP) tool for quality appraisal in qualitative evidence synthesis. Res Methods Med Health Sci. 2020. https://doi.org/10.1177/2632084320947559
20. Sollmann N, Becherucci EA, Boehm C, Husseini ME, Ruschke S, Burian E, et al. Texture analysis using CT and chemical shift encoding-based water-fat MRI can improve differentiation between patients with and without osteoporotic vertebral fractures. Front Endocrinol. 2022. https://doi.org/10.3389/fendo.2021.778537
21. Allaire BT, Lu D, Johannesdottir F, Kopperdahl D, Keaveny TM, Jarraya M, et al. Prediction of incident vertebral fracture using CT-based finite element analysis. Osteoporos Int. 2019;30(2):323–31. https://doi.org/10.1007/s00198-018-4716-1
22. Löffler MT, Jacob A, Scharr A, Sollmann N, Baum T, Ruschke S, et al. Opportunistic osteoporosis screening in multi-detector CT: Diagnostic performance in comparison to dual X-ray absorptiometry. Eur Radiol. 2019;29(9):4988–99. https://doi.org/10.1007/s00330-019-06018-w
23. Leonhardt Y, Buehring B, Hackenbroch C, Rohrmeier C, Löffler MT. Opportunistic quantitative CT predicts osteoporotic fractures better than DXA: A prospective clinical cohort study. Osteoporos Int. 2020;31(12):2395–404. https://doi.org/10.1007/s00198-020-05537-2
24. Perrier-Cornet J, Omorou AY, Fauny M, Loeuille D, Chary-Valckenaere I. Opportunistic screening for osteoporosis using thoraco-abdomino-pelvic CT-scan assessing the vertebral density in rheumatoid arthritis patients. Osteoporos Int. 2019. https://doi.org/10.1007/s00198-019-04931-w
25. Cohen A, Liu XS, Stein EM, McMahon DJ. Bone density assessment using Hounsfield units: Opportunistic screening and diagnostic considerations. J Bone Miner Res. 2021;36(5):928–37.
26. Gruenewald LD, Koch V, Martin SS, Yel I, Eichler K, Gruber-Rouh T, et al. Diagnostic accuracy of quantitative dual-energy CT-based volumetric bone mineral density assessment for the prediction of osteoporosis-associated fractures. Eur Radiol. 2022. https://doi.org/10.1007/s00330-021-08323-9
27. Kale H, Yadav S. Can routine MRI spine T1 sequences be used for prediction of decreased bone density? Acta Radiol. 2022. doi:10.1177/02841851211063008
28. Li YL, Wong KH, Law MWM, Fang BXH, Lau VWH, Vardhanabuti VV, Lam WWM. Opportunistic screening for osteoporosis in abdominal computed tomography for Chinese population. Arch Osteoporos. 2018. doi:10.1007/s11657-018-0492-y
29. Hendrickson NR, Pickhardt PJ, Del Rio AM, Rosas HG, Anderson PA. Bone mineral density T-scores derived from CT attenuation numbers (Hounsfield units): Clinical utility and correlation with dual-energy X-ray absorptiometry. Iowa Orthop J. 2018.
30. Abbouchie H, Raju N, Lamanna A, Chiang C, Kutaiba N. Screening for osteoporosis using L1 vertebral density on abdominal CT in an Australian population. Clin Radiol. 2022 Jul;77(7):e540-e548. doi:10.1016/j.crad.2022.04.002. Epub 2022 May 10. PMID: 35550303.
31. Norton EC, Dowd BE, Maciejewski ML. Odds ratios-current best practice and use. JAMA. 2018. doi:10.1001/jama.2018.6971
32. Pizzato S, Trevisan C, Lucato P, Girotti G, Mazzochin M, Zanforlini BM, et al. Identification of asymptomatic frailty vertebral fractures in post-menopausal women. Bone. 2018;113:89–94. doi:10.1016/j.bone.2018.05.007

# Appendix 1

**PRISMA 2009 checklist –** each selected study included had a checklist completed and recorded in the researcher’s dissertation file.

|  |  |  |  |
| --- | --- | --- | --- |
| **Section/topic**  | **#** | **Checklist item**  | **Reported on page #**  |
| **TITLE**  |  |
| Title  | 1 | Identify the report as a systematic review, meta-analysis, or both.  |  |
| **ABSTRACT**  |  |
| Structured summary  | 2 | Provide a structured summary including, as applicable: background; objectives; data sources; study eligibility criteria, participants, and interventions; study appraisal and synthesis methods; results; limitations; conclusions and implications of key findings; systematic review registration number.  |  |
| **INTRODUCTION**  |  |
| Rationale  | 3 | Describe the rationale for the review in the context of what is already known.  |  |
| Objectives  | 4 | Provide an explicit statement of questions being addressed with reference to participants, interventions, comparisons, outcomes, and study design (PICOS).  |  |
| **METHODS**  |  |
| Protocol and registration  | 5 | Indicate if a review protocol exists, if and where it can be accessed (e.g., Web address), and, if available, provide registration information including registration number.  |  |
| Eligibility criteria  | 6 | Specify study characteristics (e.g., PICOS, length of follow-up) and report characteristics (e.g., years considered, language, publication status) used as criteria for eligibility, giving rationale.  |  |
| Information sources  | 7 | Describe all information sources (e.g., databases with dates of coverage, contact with study authors to identify additional studies) in the search and date last searched.  |  |
| Search  | 8 | Present full electronic search strategy for at least one database, including any limits used, such that it could be repeated.  |  |
| Study selection  | 9 | State the process for selecting studies (i.e., screening, eligibility, included in systematic review, and, if applicable, included in the meta-analysis).  |  |
| Data collection process  | 10 | Describe method of data extraction from reports (e.g., piloted forms, independently, in duplicate) and any processes for obtaining and confirming data from investigators.  |  |
| Data items  | 11 | List and define all variables for which data were sought (e.g., PICOS, funding sources) and any assumptions and simplifications made.  |  |
| Risk of bias in individual studies  | 12 | Describe methods used for assessing risk of bias of individual studies (including specification of whether this was done at the study or outcome level), and how this information is to be used in any data synthesis.  |  |
| Summary measures  | 13 | State the principal summary measures (e.g., risk ratio, difference in means).  |  |
| Synthesis of results  | 14 | Describe the methods of handling data and combining results of studies, if done, including measures of consistency (e.g., I2) for each meta-analysis.  |  |
| **Section/topic**  | **#** | **Checklist item**  | **Reported on page #**  |
| Risk of bias across studies  | 15 | Specify any assessment of risk of bias that may affect the cumulative evidence (e.g., publication bias, selective reporting within studies).  |  |
| Additional analyses  | 16 | Describe methods of additional analyses (e.g., sensitivity or subgroup analyses, meta-regression), if done, indicating which were pre-specified.  |  |
| **RESULTS**  |  |
| Study selection  | 17 | Give numbers of studies screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally with a flow diagram.  |  |
| Study characteristics  | 18 | For each study, present characteristics for which data were extracted (e.g., study size, PICOS, follow-up period) and provide the citations.  |  |
| Risk of bias within studies  | 19 | Present data on risk of bias of each study and, if available, any outcome level assessment (see item 12).  |  |
| Results of individual studies  | 20 | For all outcomes considered (benefits or harms), present, for each study: (a) simple summary data for each intervention group (b) effect estimates and confidence intervals, ideally with a forest plot.  |  |
| Synthesis of results  | 21 | Present results of each meta-analysis done, including confidence intervals and measures of consistency.  |  |
| Risk of bias across studies  | 22 | Present results of any assessment of risk of bias across studies (see Item 15).  |  |
| Additional analysis  | 23 | Give results of additional analyses, if done (e.g., sensitivity or subgroup analyses, meta-regression [see Item 16]).  |  |
| **DISCUSSION**  |  |
| Summary of evidence  | 24 | Summarize the main findings including the strength of evidence for each main outcome; consider their relevance to key groups (e.g., healthcare providers, users, and policy makers).  |  |
| Limitations  | 25 | Discuss limitations at study and outcome level (e.g., risk of bias), and at review-level (e.g., incomplete retrieval of identified research, reporting bias).  |  |
| Conclusions  | 26 | Provide a general interpretation of the results in the context of other evidence, and implications for future research.  |  |
| **FUNDING**  |  |
| Funding  | 27 | Describe sources of funding for the systematic review and other support (e.g., supply of data); role of funders for the systematic review.  |  |

*From:*  Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group (2009). Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. PLoS Med 6(7): e1000097. doi:10.1371/journal.pmed1000097 [**www.prisma-statement.org**](http://www.prisma-statement.org).

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# Appendix 2

**PART ONE: All studies, methods, and results.**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Author/year** | **Sample characteristics** | **Study design** | **Outcomes reviewed / measured** | **Key results** | **Key conclusions**  |
| Abbouchie et al. (2022) | Patients greater than or equal to 30 years undergoing abdominal CT and DXA within 12 months were assessed retrospectively. Bone mineral density (BMD) was measured using axial CT attenuation at L1, correlating with DXA T-scores. Sensitivity, specificity, area under the curve (AUC), and odds ratio (OR) were calculated | Retrospective study | Outcome measured:* Osteoporosis
* Bone mineral density
 | The study cohort comprised 407 CT DXA pairs (58.2% women). The prevalence of osteoporosis was 11.8%. L1 density and T-score were significantly correlated in both women (r¼0.35, p<0.01). CT L1 attenuation correlates with L1 DXA T-scores. Density values < 190 and 180 HU increased the probability of an osteoporosis diagnosis in Australian women and the overall cohort, respectively. | Opportunistic screening for osteoporosis using abdominal CT is feasible, enabling identification of at-risk subjects for formal DXA imaging, thereby improving treatment initiation, and reducing fracture risk. |
| Allaire et al. (2019) | 26 incident VF cases (13 men, 13 women) and 62 age- and sex-matched controls aged 50 to 85 years were selected from the Framingham multi-detector computed tomography cohort. Vertebral compressive strength, integral vBMD, trabecular vBMD, CT-based BMC, and CT-based aBMD were measured from CT scans of the lumbar spine. | case-control study | Outcome measured:* Vertebral fracture
* Bone mineral density
 | Lower vertebral strength at baseline was associated with an increased risk of new or worsening VF after adjusting for age, BMI, and prevalent VF status (odds ratio (OR) = 5.2 per 1 SD decrease, 95% CI 1.3–19.8). Area under receiver operating characteristic (ROC) curve comparisons revealed that vertebral strength better predicted incident VF than CT-based aBMD (AUC = 0.804 vs. 0.715, p = 0.05) but was not better than integral vBMD (AUC = 0.815) or CT-based BMC (AUC = 0.794). Additionally, proposed fragile bone strength thresholds trended toward better sensitivity for identifying VF than that of aBMD classified osteoporosis (0.46 vs. 0.23, p = 0.09) | This study shows an association between vertebral strength measures and incident vertebral fracture in men and women. Though limited by a small sample size, our findings also suggest that bone strength estimates by CT-based FEA provide equivalent or better ability to predict incident vertebral fracture compared to CT-based aBMD. Our study confirms that CT-based estimates of vertebral strength from FEA are useful for identifying patients who are at high risk for vertebral fracture. |
| Cohen et al. (2021) | Consecutive patients who had undergone CT and dual-energy X-ray absorptiometry (DXA) test of the lumbar spine within 6 months were included in this retrospective study. Hounsfield units (HU) on lateral lumbar spine CT and BMD at the spine and hip on DXA were compared. Potential HU thresholds suggestive of abnormal BMD were established using receiver operating characteristic (ROC) analysis | Retrospective study | Outcome measured:* Osteoporosis
* Bone mineral density
* Vertebral fracture
 | 246 patients (mean age of 64 ± 11.6 years; 83 % female) were included. On DXA, 27 % had osteoporosis, 56 % had osteopenia, and 17 % had normal BMD. To distinguish osteoporosis from non-osteoporosis (osteopenia, normal BMD), a threshold of HU160 had sensitivity 95 % and the balanced threshold was HU121 (sensitivity 74 %, specificity 61 %). To distinguish normal from abnormal BMD (osteoporosis, osteopenia), a threshold of HU110 had specificity 93 % and the balanced threshold was HU149 (sensitivity 76 %, specificity 74 %). | In a heterogeneous Middle-Eastern population, our study supports the reported correlation between HU values on lumbar spine CT and BMD on DXA. In this population, HU > 160 correlates with low probability of osteoporosis on DXA, and screening examination is not warranted unless a vertebral fracture is detected; for HU ≤ 110 there is high probability of abnormal (osteoporosis or osteopenia) BMD, DXA examination is warranted; Finally, for HU 110–160, there is an intermediate chance of abnormal BMD, DXA examination may be warranted in specific patients with other risk factor |
| Gruenewald et al. (2022) | L1 of 92 patients (46 men, 46 women; mean age, 64 years, range, 19–103 years) who had undergone third-generation dual-source DECT between 01/2016 and 12/2018 was retrospectively analysed. For phantomless BMD assessment, dedicated DECT postprocessing software using material decomposition was applied. Digital files of all patients were sighted for 2 years following DECT to obtain the incidence of osteoporotic fractures. Receiver operating characteristic (ROC) analysis was used to calculate cut-of values and logistic regression models were used to determine associations of BMD, sex, and age with the occurrence of osteoporotic fractures | Retrospective cohort study | Outcome measured:* Bone mineral density measurement
* Osteoporotic fractures
 | A DECT-derived BMD cut-off of 93.70 mg/cm3 yielded 85.45% sensitivity and 89.19% specificity for the prediction to sustain one or more osteoporosis-associated fractures within 2 years after BMD measurement. DECT-derived BMD was significantly associated with the occurrence of new fractures (odds ratio of 0.8710, 95% CI, 0.091–0.9375, p<.001) indicating a protective effect of increased DECT – derived BMD values. Overall AUC was 0.9373 (CL, 0.867-0.977, p <0.001) for the differentiation of patients with sustained osteoporosis-associated fractures within 2 years of BMD assessment | Retrospective DECT-based volumetric BMD assessment can accurately predict the 2-year risk to sustain an osteoporosis-associated fracture in at-risk patients without requiring a calibration phantom. Lower DECT-based BMD values are strongly associated with an increased risk to sustain fragility fractures. |
| Hendrickson et al. (2018) | Retrospective single centre cohort study of patients undergoing CT of the lumbar spine. Reference values for lumbar spine Hounsfield units were determined from a reference sample of 190 young women aged 20-30 years undergoing CT scan of the lumbar spine. A separate sample of 252 older subjects undergoing CT and dual-energy X-ray absorptiometry (DXA) within a 6-month period that served as a validation cohort. Osteoporosis was defined by T-score DXA ≤ -2.5. Reference values were determined for lumbar HU from L1 to L4 from the reference cohort (24.0 ± 2.9 years). T-score HU was calculated in the validation cohort (58.9 ± 7.5 yrs.). Receiver operating characteristic (ROC) curves were used to assess sensitivity and specificity of T-score HU for this task. | Retrospective cohort study | Outcome measured:* Osteoporosis screening
* Bone mineral density
* Fracture risk
 | Reference group HU ranged from 227 ± 42 at L3 to 236 ± 42 at L1 (P < 0.001). Validation group T-score DXA was -0.7 ± 1.5 and -0.9 ± 1.2 at lumbar and femoral sites respectively. Mean T-score HU was -2.3. T-score HU of -3.0, corresponding to 110 HU, was 48% sensitive and 91% specific for osteoporosis in the validation group. ROC area under the curve ranged from 0.825 to 0.853 depending on lumbar level assessed. | Although lumbar trabecular HU T scores are lower than DXA T-scores, thresholds can be selected to achieve high sensitivity and specificity when screening for osteoporosis. Patients with a lumbar T-score HU ≤ -3.0 should be referred for additional evaluation. Further research into HU T-scores and clinical correlates may also provide a tool to assess changes in vertebral bone and the relationship to fracture risk across the lifespan.  |
| Hsieh et al. (2021) | 5164 and 18175 patients (aged 40 – 49 years) with pelvis/lumbar spine radiographs and Hologic DXA. The area under the precision-recall curve and accuracy are 0.89 and 91.7% for hip osteoporosis, 0.89 and 86.2% for spine osteoporosis, 0.83 and 95.0% for high 10-year major fracture risk, and 0.96 and 90.0% for high hip fracture risk.  | Retrospective Cohort study | Outcome measures:* Evaluation of fracture risk using plain radiographs
* Identification of fractures
* Bone Mineral density prediction
* Osteoporosis
 | From 2006 to 2020, 30,958 and 86,977 patients aged 40–90 years with paired DXA-pelvis or paired DXA-lateral radiographs of the lumbar spine (18.6% and 18.2% of patients with hip or lumbar spine radiographs) were screened to identify hip and spine cohorts for analysis. The final study population included 5164 patients (3997 women [77.4%], mean age, 72.2 [standard deviation, SD, 11.2] years) in the hip testing set and 18,175 patients (14,469 women [79.6%], mean age, 67.1 [SD, 10.6] years) in the spine testing set. The median time between DXA and plain radiographs was 29 and 16 days, respectively. The DXA identified 1110 patients (21.5%) in the hip and 7860 patients (43.3%) in the spine cohort as osteoporotic. | The tool classifies 5206 (84.8%) patients with 95% positive or negative predictive value for osteoporosis, compared to 3008 DXA conducted at the same study period. |
| Johannesdottir et al. (2020) | 135 cases (community men and women) with incident vertebral fracture at any level and 266 age- and sex-matched controls. We used baseline CT scans to measure integral and trabecular volumetric bone mineral density (vBMD) and vertebral strength (via finite element analysis, FEA) at the T8 and L2 levels. Association between these measurements and vertebral fracture was determined by using conditional logistic regression. Sensitivity and specificity for predicting incident vertebral fracture were determined for lumbar spine and thoracic bone measurements | Case control study | Outcome measured:* Vertebral fracture
* Bone mineral density
* Osteoporosis screening
 | Bone measurements from T8 and L2 predicted incident vertebral fracture equally well, regardless of fracture location. Specifically, for predicting vertebral fracture at any level, the odds ratio (per 1-SD decrease) for the vBMD and strength measurements at L2 and T8 ranged from 2.0 to 2.7 (p < 0.0001) and 1.8 to 2.8 (p < 0.0001), respectively. Results were similar when predicting fracture only in the thoracic versus the thoracolumbar spine. Lumbar and thoracic spine bone measurements had similar sensitivity and specificity for predicting incident vertebral fracture. | These findings indicated that like those from the lumbar spine, CT-based bone density and strength measurements from the thoracic spine may be useful for identifying individuals at high risk for vertebral fracture |
| Kale & Yadav (2022) | To evaluate whether T1 signal intensity (SI) ratio of lumbar vertebral body (VB)/cerebrospinal fluid (CSF) may predict decreased bone density. A retrospective study was conducted. After use of inclusion/exclusion criteria, 36 patients who had an MRI scan of the lumbar spine and a DEXA scan performed as a part of annual health visit were selected. T1 SI of the lumbar vertebral bodies and adjacent CSF were recorded. Ratio of T1 SI of L1–L4 (VB)/CSF was calculated. The corresponding bone-density values on DEXA scan measured as g/cm2 were obtained. Pearson’s r correlation statistic was used to determine the correlation between these variables | Retrospective study | * Bone Mineral Density
* Osteoporosis
 | T1 VB/T1 CSF SI ratio was between 1.308 and 2.927 (mean = 2.028). Mean T1 SI value of vertebral bodies (L1– L4) was 264.9 and mean CSF SI value was 131.9. Bone density in g/cm2 was between 0.851 and 1.398 (mean = 1.081). Pearson correlation coefficient was r=−0.619 (P=0.0001), which shows a negative moderate correlation between the T1 VB/T1 CSF SI ratio and bone density | A high T1 VB/T1 CSF SI ratio on routine MRI sequences may indicate decreased bone density. This ratio may be of substantial benefit in unsuspected osteoporosis/osteopenia on routine MRI lumbar spine imaging |
| Leonhardt et al. (2020) | 58 patients (73 ± 11 years, 72% women) were identified that had at least one prevalent low-energy fracture and had undergone CT of the spine. BMD was determined by converting HU using scanner specific conversion equations. Baseline DXA was available for 31 patients. During a 3-year follow-up, new fractures were diagnosed either by (i) recent in-house imaging or (ii) clinical follow-up with validated external reports. Associations were assessed using logistic regression models, and cut-off values were determined with ROC/Youden analyses. | Prospective cohort study | Outcome measured:* Fracture risk
* Osteoporosis
* Opportunistic bone mineral density
 | Within 3 years, 20 of 58 patients presented new low-energy fractures (34%). Mean QCT BMD of patients with fractures was significantly lower (56 ± 20 vs. 91 ± 38 mg/cm3 ; p = 0.003) and age was higher (77 ± 10 vs. 71 ± 11 years; p = 0.037). QCT BMD was significantly associated with the occurrence of new fractures, and the OR for developing a new fracture during follow-up was 1.034 (95% CI, 1.010–1.058, p = 0.005), suggesting 3% higher odds for every unit of BMD decrease (1 mg/cm3 ). Age and sex showed no association. For the differentiation between patients with and without new fractures, ROC showed an AUC of 0.76 and a Youden’s Index of J = 0.48, suggesting an optimal cut-off value of 82 mg/cm3 . DXA T-scores showed no significant association with fracture occurrence in analogous regression models. | In this use case, opportunistic BMD measurements attained through QCT predicted fractures during a 3-year follow-up. This suggests that opportunistic measurements are useful to reduce the diagnostic gap and evaluate the fracture risk in osteoporotic patients. |
| Li et al. (2018) | 109 Chinese patients who concomitantly underwent abdominal CT and dual X-ray absorptiometry (DXA) within 6 months between July 2014 and July 2017 at a university hospital in Hong Kong. Images were retrospectively reviewed on sagittal reformats, and region-of-interest (ROI) markers were placed on the anterior portion of each of the L1–L5 vertebra to measure the HU. The mean values of CT HU were then compared with the bone mineral density (BMD) and T-score obtained by DXA. Receiver operator characteristic (ROC) curves were generated to determine diagnostic cut-off thresholds and their sensitivity and specificity values. | Retrospective study | Outcome measured:* Osteoporosis diagnosis
* Prevention of osteoporotic fracture
* Bone mineral density
 | The mean CT HU differed significantly (p < 0.01) for the three DXA-defined BMD categories of osteoporosis (97 HU), of osteopenia (135 HU), and of normal individuals (230 HU). There was good correlation between the mean CT HU and BMD and T-score (Pearson coefficient of 0.62 and 0.61, respectively, p < 0.001). The optimal cut-off point for exclusion of osteoporosis or osteopenia was HU ≥ 175 with negative predictive value as 98.9% and with area under curve (AUC) of ROC curve as 0.97. The optimal cut-off point for diagnosis of osteoporosis was HU ≤ 136 with positive predictive value as 81.2% and with AUC of ROC curve as 0.86 | This is the first study on osteoporosis diagnosis with routine CT abdominal scans in Chinese population. The cut-off values were comparable with previous studies in Caucasian populations suggesting generalizability. Radiologists should consider routinely reporting these opportunistic findings to facilitate early detection and treatment of osteoporosis to prevent fractures and related complications |
| Löffler et al. (2019) | 84 patients aged 50 years and older, who had routine CT including the lumbar spine and DXA within a 12-month period (baseline) as well as follow-up imaging after at least 12 months or who sustained an incident vertebral fracture documented earlier. Patients with bone disorders aside from osteoporosis were excluded. Fracture status and trabecular bone mineral density (BMD) were retrospectively evaluated in baseline CT and fracture status was reassessed at follow-up. BMDQCT was assessed by opportunistic QCT with asynchronous calibration of multiple MDCT scanners | Retrospective observational study | Outcome measured:* Osteoporosis
* Fracture
* Bone mineral density
 | Sixteen patients had incident vertebral fractures showing lower mean BMDQCT than patients without fracture (p = 0.001). For the risk of incident vertebral fractures, the hazard ratio increased per SD in BMDQCT (4.07; 95% CI, 1.98–8.38), as well as after adjusting for age, sex, and prevalent fractures (2.54; 95% CI, 1.09–5.90). For DXA, a statistically significant increase in relative hazard per SD decrease in T-score was only observed after age and sex adjustment (1.57; 95% CI, 1.04–2.38). The predictability of incident vertebral fractures was good by BMDQCT (AUC = 0.76; 95% CI, 0.64–0.89) and non-significant by T-scores. Asynchronously calibrated CT scanners showed good long-term stability (linear drift ranging from − 0.55 to − 2.29 HU per year). | Opportunistic screening of mainly neurosurgical and oncologic patients in CT performed for indications other than densitometry allows for better risk assessment of imminent vertebral fractures than dedicated DXA. |
| Perrier-Cornet et al. (2019) | Consecutive RA patients who underwent a CT-scan and DXA within a 2-year period were retrospectively included. The CT sagittal images were then evaluated for vertebral fractures from T4 to L5 using the Genant classification. The CT-attenuation values (in Hounsfield units (HU)) of trabecular bone in L1 were measured on axial images and compared to the DXA results | Retrospective cohort study | Outcome measured:* Osteoporosis
* Osteoporotic fracture
* Bone mineral density
 | This study included 105 patients (mean age 61.1 years (± 9.5), 78.1% women). There were 28 patients (26.7%) with DXA-defined osteoporosis and 32 (30%) with osteoporotic fractures (vertebral and/or non-vertebral). The CT assessment indicated that the mean (SD) vertebral L1 attenuation was 142.2 HU (± 18.5). The diagnostic performance for the vertebral CT-attenuation measurement was acceptable: the AUC was 0.67 for predicting osteoporotic fractures and of 0.69 for predicting vertebral fractures. Among patients with osteoporotic fractures, there were 23 (74%) patients categorized as osteoporotic with a L1 CT-attenuation of 135 HU or less, whereas there were only 13 patients (42%) identified by DXA. | CT offers a combined opportunistic screening for osteoporosis by assessing both vertebral fractures and bone density on routine CT-scans. This approach may be particularly interesting for RA patients with a high osteoporosis risk |
| Pizzato et al. (2018) | 1132 post-menopausal women referred to the osteoporosis outpatient clinic of the Geriatrics Department of Padova. For each participant assessed: anthropometric data, femoral and lumbar bone mineral density (BMD), dorso-lumbar X-rays, bone metabolism markers.  | Retrospective case control | Outcome measured:* Lumbar vertebral fractures
* Bone mineral density
* Osteoporosis
 | Of the women included in our study, 28% presented vertebral fractures, most of these previously unknown (82.8%). Lumbar BMD did not differ between patients with and without vertebral fractures. According to SIOMMMS guidelines, 50% of patients < 60 years with unknown vertebral fractures would have been excluded from spinal X-ray examination. According to ISCD recommendations, the number of patients excluded reached 94.6% in the < 60 age-group and 84.9% in the 60–70 age-group. The under-identification of vertebral fractures led to the 10-year risk of fractures computed by DeFRA being underestimated by around 15% | BMD, particularly in the lumbar site, may not properly predict the presence of vertebral fractures in post-menopausal women. Improvement of the current recommendations for spinal X-ray examination may lead to early identification and better management of patients with vertebral fractures |
| Sollmann et al. (2022) | Twenty-six patients (15 females, median age: 73 years, 11 patients showing at least one osteoporotic vertebral fracture) who had CT and 3-Tesla chemical shift encoding-based water-fat MRI (CSE-MRI) available were analysed. In total, 171 vertebral bodies of the thoracolumbar spine were segmented using an automatic convolutional neural network (CNN)-based framework, followed by extraction of integral and trabecular vBMD using CT data. For CSE-MRI, manual segmentation of vertebral bodies and consecutive extraction of the mean proton density fat fraction (PDFF) and T2\* was performed. First-order, second-order, and higher-order texture features were derived from texture analysis using CT and CSE-MRI data. Stepwise multivariate linear regression models were computed using integral vBMD and fracture status as dependent variables. | Retrospective cohort study | Outcome measured:* Osteoporotic vertebral fracture
* Bone mineral density
 | Patients with osteoporotic vertebral fractures showed significantly lower integral and trabecular vBMD when compared to patients without fractures (p<0.001). For the model with integral vBMD as the dependent variable, T2\* combined with three PDFF based texture features explained 40% of the variance (adjusted R2 ½R2 a= 0.40; p<0.001). furthermore, regarding the differentiation between patients with and without osteoporotic vertebral fractures, a model including texture features from CT and CSE-MRI data showed better performance than a model based on integral vBMD and PDFF only (R2 a = 0.47 vs. R2 a = 0.81; included texture features in the final model: integral vBMD, CT\_Shortrun\_emphasis, CT\_Varianceglobal, and PDFF\_Variance). | Using texture analysis for spine CT and CSE-MRI can facilitate the differentiation between patients with and without osteoporotic vertebral fractures, implicating that future fracture prediction in osteoporosis may be improved |

**PART TWO: CASP checklists**

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| CASP checklists |
| Publication | Focussed issue? | Acceptable recruitment? | Exposure accurately measured to minimise bias? | Outcome accurately measured to minimise bias? | Confounding factors considered? | Confounding factors considered in design& analysis | Complete FU? | FU long enough? | Results info | Precision of results?  | Believable results?  | Local applicability? | Results fit other evidence.  | Implications? |
| Abbouchie et al. (2022) | Y | Y | Y | Y | Y | Y | n/a | n/a | 2 | 2 | Y | Y | Y | C |
| Allaire et al. (2019) | Y | Y | Y | Y | Y | Y | n/a | n/a | 2 | 2(CI) | Y | Y | Y | Y |
| Cohen et al. (2021) | Y | Y | Y | Y | Y | Y | n/a | n/a | 2 | 2(CI) | Y | Y | Y | C |
| Gruenewald et al. (2022) | Y | Y | N | Y | Y | Y | C | N | 2 | 2(CI) | C | Y | C | Y |
| Hendrickson et al. (2018) | Y | Y | Y | Y | Y | Y | n/a | n/a | 2 | 2(CI) | Y | Y | Y | C |
| Hsieh et al. (2021) | Y | Y | Y | Y | Y | Y | n/a | n/a | 2 | 2(CI) | Y | Y | Y | Y |
| Johannesdottir et al. (2020) | Y | Y | Y | Y | Y | Y | n/a | n/a | 2 | 2(CI) | Y | Y | Y | C |
| Kale & Yadav (2022) | Y | Y | Y | Y | Y | Y | n/a | n/a | 2 | 2(CI) | Y | Y | C | C |
| Leonhardt et al. (2020) | Y | Y | Y | Y | Y | Y | Y | Y | 2 | 2(CI) | Y | Y | Y | Y |
| Li et al. (2018) | Y | Y | Y | Y | Y | Y | n/a | n/a | 2 | 2(CI) | Y | Y | Y | C |
| Löffler et al. (2019) | Y | Y | N | Y | Y | Y | N | N | 2 | 2(CI) | Y | Y | Y | Y |
| Perrier-Cornet et al. (2019) | Y | Y | Y | Y | Y | Y | C | N | 2 | 2(CI) | Y | Y | Y | C |
| Pizzato et al. (2018) | Y | Y | Y | Y | Y | Y | n/a | n/a | 2 | 2(CI) | Y | Y | Y | C |
| Sollmann et al. (2022) | Y | Y | Y | Y | Y | Y | n/a | n/a | 2 | 1 | Y | Y | Y | Y |
| Y= yes, N= no, C= Cannot Tell, 2=good detail, 1=some detail, 0=no detail provided(CI)=Confidence Levels, n/a = not applicable |