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REVIEW ARTICLE

Assessing bone quality in hounsfield units using computed tomography: what value should be used to classify bone as normal or osteoporotic?

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Abstract

Purpose The purpose of this study was to investigate threshold values for classifying bone as normal or osteoporotic based on Computed Tomography (CT) Hounsfield Units (HU) and to determine if clinically applicable values could be derived to aid spine surgeons evaluating bone quality using CT.

Methods This literature review was completed using PubMed and Ovid (MedLine), using syntax specific to bone quality and CT. The included articles were original clinical studies assessing bone quality and utilized composite L1-L4 HU values compared against dual-energy X-ray absorptiometry (DEXA) values. Extracted data study descriptors, CT measurement technique, and CT threshold values. CTs were measured from L1-L4 using either axial or sagittal images, and must classify their bone quality findings for any of the following 3 categories: normal, osteopenia, or osteoporosis.

Results This review located 34 studies measuring bone density using CT with threshold values, of which, 10 were included in the final review. Number of patients ranged from 74 to 283 and cohort ages from 20s to 70.6 years. CT threshold values for assessing normal and osteoporotic bone quality ranged from 150 to 179 and 87 to 155, respectively. From combining values across studies, a HU value of ≥170 HU was associated with normal bone and ≤115 HU with osteoporosis.

Conclusion There is variation in HU values used to differentiate normal from compromised bone quality, even after limiting studies. For patients with HU values between or near 170 or 115 HU, a DEXA scan may be warranted for further evaluation. With ongoing investigation in this area, threshold values for classifying bone quality using CT will be continually refined.

Keywords Bone density · Computed tomography · Classification · Lumbar spine

Introduction

Evaluating vertebral bone quality prior to spinal surgery is important in order to increase the likelihood of successful instrumentation. There are many potential complications regarding instrumentation in patients with poor bone quality including implant subsidence, pedicle screw pullout, and vertebral body fracture [1–3]. Realizing the importance of good bone quality, dual-energy x-ray absorptiometry (DEXA) has been used to assess bone mineral density (BMD) prior to spinal surgery and has remained the gold standard for classifying bone as normal, osteopenic, or osteoporotic [4]. There are possible shortcomings of DEXA, such as incorporating osteophytic and cortical bone within the BMD values [5]. Due to this realization,, as well as the cost, radiation exposure, and inconvenience for patients to get a DEXA scan, there has been increasing interest in using other modalities for measuring bone density, namely computed tomography (CT) or magnetic resonance imaging (MRI) [6, 7]. Spine surgery candidates commonly undergo these preoperative scans, which provides opportunistic resources to measure bone quality instead of or in addition to DEXA.

The interest in these alternative methods to assess bone quality has generated numerous studies of varying measurement techniques, regions of interest, and study populations [8–11]. These variations appear across the scientific literature, often using alternative equations for deriving

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composite or singular bone quality values, using contrasted scans, combining values from a multitude of scans, and alternative imaging views when performing measurements, such as sagittal versus axial [12–15]. This influx of data has produced a large range of values for classifying patients as having normal or compromised bone. Threshold values must be identified with some standardized criteria as to measurement technique and population composition to be of better use in the clinical setting.

CT, from which bone density is measured using Hounsfield units (HU), is known to provide a direct assessment of bone quality through programs such as the Picture Archiving and Communication System (PACS). The lack of standardization has made it difficult for spine care providers to interpret CT HU values to classify bone quality. The purpose of this study was to investigate the reported threshold values for classifying bone as normal or osteoporotic and to determine if clinically applicable values could be derived to aid spine care providers evaluating bone quality using CT.

Methods

Search strategy

A literature search was conducted using PubMed and Ovid (MedLine), using syntax specific to lumbar spine, bone quality and CT scans. The search was completed on these databases from inception to the search conclusion in January 2024. Articles were included if they were (1) original clinical studies, (2) involved a lumbar spinal population or available lumbar spine imaging, (3) utilized composite CT values derived from L1-L4 using either the axial or sagittal images, and (4) compared their CT composite values against DEXA to classify their bone quality findings in any of the following 3 categories: normal, osteopenia, or osteoporosis. Publications could be from any date or publication location.

Data collection

Data collected from the eligible studies included: patient population type, average study population age, number of patients involved in the study, the CT measurement technique, and the CT threshold values for differentiating normal from compromised bone quality. Two study members examined the studies for inclusion and subsequent data collection.

Articles were coded using the following process: first author's name followed by the publication date. This process allowed for the correct identification and differentiation of repeating author names or dates.

Data Analysis

A composite threshold HU value for L1-L4 for classifying patients as having normal or osteoporotic bone quality was derived by calculating the weighted mean values reported in each of the articles providing these respective thresholds.

Search outcome

This search found 41 studies assessing bone density using CT and provided threshold values for classifying bone quality. Among these 41 studies, 7 were excluded as they did not include spine values, and an additional 24 were excluded due to not providing a L1-L4 composite value. In all studies, an oval region of interest was drawn on the cancellous bone in the axial or sagittal view of the vertebral body. This was done for all lumbar vertebrae (L1-L4) and averaged together to yield a composite value.

Results

Included studies overview

The 10 included studies reported on a total of 1,627 patients. The patient populations included degenerative lumbar spine and nonspecific pathology (CTs including the lumbar spine but not necessarily performed on patients with spinal problems). The number of patients included in each study ranged from 74 to 283 and the ages of these cohorts ranged from 20s to 70.6 years (Table 1). Of note, the included studies only spanned the previous 7 years, ranging in publication dates from 2016 to 2023.

Bone density findings

Threshold values for assessing normal bone quality using CT ranged from 150 to 179 (Table 1). Osteoporosis was classified as ranging from 91.5 to 155 HU. Osteopenia was very rarely defined using CT in these studies. Based on calculating a weighted value across the studies, it is estimated that a HU value of ≥170 HU is associated with normal bone. The values for classifying a patient as having osteoporosis were quite variable, but a value of ≤115 HU was calculated based on weighted means, though some studies had much higher values.

Table 1 Studies and their classifications of bone quality derived from lumbar CT HU

Characteristics						Thresholds		
Study	Year	N	Mean Age (years)	Population pathology	View measured (axial, sagittal)	Normal	Osteopenic	Osteo-porotic
Aynaszyan et al. [16]	2023	74	70.6	Spinal surgery candidates	Sagittal and axial midbody L1-L4	n/r	n/r	< 110
Choi et al. [17]	2016	110	51.4 (degeneration) and 67.5 (non-degeneration)	110 (80 non-degenerative and 30 degenerative)	Axial midbody L1-L4	> 150	150 – 100	< 100
Cohen et al. [18]	2021	246	64	Nonspecific pathology	Sagittal and axial midbody L1-L4	> 160	n/r	< 110
Courtois et al. [19]	2024	283	47	Lumbar total disc replacement candidates	Axial midbody L1-L4	> 179	n/r	n/r
Eljarni et al. [20]	2021	100	60.25	19 degenerative and 81 nonspecific spinal pathology	Sagittal (5 regions) and axial midbody L1-L4	> 177	132	106
Hendrickson et al. [21]	2018	190	20–30 in reference group and 58.9 in validation cohort	442 (190 spinal reference group and 252 validation cohort)	Axial midbody L1-L4	n/r	n/r	< 110
Luo et al. [22]	2023	210	69	Nonspecific pathology	Axial midbody L1-L4	n/r	n/r	< 95
Wongsuttil-ert et al. [23]	2023	205	n/r	Spine patients either male or menopausal female > 50)	Axial midbody L1-L4	n/r	n/r	< 155
Yang et al. [24]	2022	100	60.8	Nonspecific pathology	3 Axial (upper, midbody, lower) L1-L4	158.75	n/r	91.6
Yan-Lin et al. [25]	2018	109	67	Nonspecific pathology	Axial midbody L1-L4	> 175	n/r	< 136

Discussion

The purpose of this literature review was to investigate reported threshold values for classifying lumbar vertebral bone as normal or osteoporotic and to determine if clinically applicable values could be derived to aid spine surgeons evaluating bone quality using CT. Combining the HU values across multiple studies, it was calculated that HU values $\geq$170 HU were associated with normal bone and HU values $\leq$115 HU were indicative of osteoporosis. Most of the studies did not specifically address osteopenia, but threshold values for it may be implied to fall between the values for normal and osteoporotic bone. This is congruent with other literature, for example, a systematic review by Deshpande et al. found that CT HU values > 160 demonstrated significantly reduced risk of osteoporosis and values < 110 were significantly correlated with osteoporosis [26].

There are beneficial aspects for using CT to generate bone quality measurements. CTs are opportunistically available, as many spine surgery patients scheduled to receive an implanted device receive a scan prior to surgery, and patients will not have increased radiation exposure by undergoing a DEXA. Moreover, the CT measurement technique is simple and allows for rapid bone quality results. There is also a savings of the cost of the scan and patients are not inconvenienced by having an additional appointment for a DEXA. Another beneficial aspect of using these opportunistic scans is that they do not require multiple calculations. CT bone quality values already correlate to the patient's imaging regardless of age or sex, whereas DEXA z-scores have to be adjusted against a standardized BMD from what is expected of other patients in the same demographic categories.

Even with an attempt at regulating measurement techniques and study populations, variability is still likely to occur due to factors such as CT scan settings used. This factor may be behind the continued variation in threshold values, even after uniform study methods. Pickhardt et al. discussed a possible solution to varied CT scanner calibration settings, proposing an asynchronous phantom calibration to calculate areal BMD and correlate with clinical CT scans [27]. But this falls outside of the clinical use of greatest interest which is using clinically available CT scans to assess bone quality.

A limitation of this study was the lack of systematic search methodology, which is inherent to literature reviews. The records were located using most relevant results only, but it is still possible that eligible studies were not assessed for inclusion. Part of the reason why DEXA is the standard is that each patient's measurements are compared against a large, comprehensive database of patients that were conducted on a scanning machines using the same calibration settings, which allows for more reliable threshold values. The current study used smaller study populations based on a wide variety of CT scanners and measurement methods, which were used to derive threshold values. While these values are not promoted as firm thresholds, there is a hope that these findings may provide clinical guidance. Additionally, a more in-depth analysis of a greater pool of study data, using a more advanced analysis than in the current study, would allow for more refined threshold values. A strength of this study was the rigid inclusion and exclusion criteria, which allowed for the adequate compilation of each study's findings. Through these criteria, the authors were able to identify a reasonable standardization approach to assessing this data within this growing field.

There are other reported uses of CT scans to assess bone quality, in addition to the aforementioned uses prior to undergoing spine surgery. Murata et al. experimented with CT and incidence of vertebral fracture risk in elderly populations while Li et al. used CT to measure the planned screw trajectory in order to better predict pedicle screw pullout [28, 29]. In addition to CT, qualitative CT (QCT) has been used to measure bone quality and is said to more accurately capture the bone's microarchitecture than DEXA; however, the QCT exposes patients to much higher doses of radiation [30]. QCT may correlate better but CT are more widely used, which makes measurement techniques on CT more clinically useful. Hopefully, the methodology using CT will be more refined over time.

In addition to CT, a number of studies have also tested MRI's ability to measure bone quality, derived from vertebral bone quality (VBQ). There is also quite a bit of variation when measuring bone density, similarly seen with CT. Roch et al. found that VBQ significantly correlated with CT bone quality values, although they used alternative equations for deriving VBQ values [13]. Kale et al. found a moderate correlation between their measure of VBQ and DEXA, and concluded that MRI has the potential to predict decreased bone density, however, specifically pertaining to high VBQ values [31].

As discussed above, there are important advantages to using CT, but with these many study variations, the clinical utility of using these scans becomes slightly onerous [32]. Standardization is necessary to draw conclusions in this constantly-changing field of study. With more studies assessing bone quality using strict study parameters, there are hopes that more refined thresholds may be calculated and utilized in the clinical setting [33].

Conclusion

There is quite a bit of variation in the HU values used to differentiate normal from compromised vertebral bone quality, even when limiting studies to spine populations and using a composite score for L1 to L4. As found in the current study, combining values from multiple studies may provide guidance in assessing bone quality prior to spine surgery. For patients with values between or near 170 HU for normal bone or 115 HU for osteoporosis, as found in the current study, a DEXA scan may be warranted for further evaluation. It is hope that these composite values will help provide clinicians guidance in interpreting HU values for assessing bone quality rather than depending on values provided in a single article. With ongoing investigations in this area, the threshold values for classifying normal and osteoporotic bone will be continually refined.

Declarations

Conflict of interest No funding was received for this study and neither author has a conflict of interest to disclose for this study.

References

1. Bertagnoli R et al (2005) Complications and strategies for revision surgery in total disc replacement. Orthop Clin North Am 36(3):389–395
2. Jones C et al (2022) The predictive value of a novel site-specific MRI-based bone quality assessment, endplate bone quality (EBQ), for severe cage subsidence among patients undergoing standalone lateral lumbar interbody fusion. Spine J 22(11):1875–1883
3. Sakai Y et al (2018) Hounsfield unit of screw trajectory as a predictor of pedicle screw loosening after single level lumbar interbody fusion. J Orthop Sci 23(5):734–738
4. Krugh M, Langaker MD (2023) *Dual-Energy X-Ray Absorptiometry*, in *StatPearls*. StatPearls Publishing. Copyright © 2023, StatPearls Publishing LLC.: Treasure Island (FL)
5. Masud T et al (1993) Effect of spinal osteophytosis on bone mineral density measurements in vertebral osteoporosis. BMJ 307(6897):172–173
6. Ahmad A et al (2023) Correlation between bone density measurements on CT or MRI versus DEXA scan: a systematic review. NASSJ 14:100204
7. Kim AYE et al (2023) MRI-based score for Assessment of Bone Mineral density in Operative Spine patients. Spine 48(2):107–112
8. Kohan EM et al (2017) Lumbar computed tomography scans are not appropriate surrogates for bone mineral density scans in primary adult spinal deformity. Neurosurg Focus 43(6):E4
9. Johnson CC et al (2016) Using Hounsfield units to assess osteoporotic status on wrist computed Tomography scans: comparison with Dual Energy X-Ray Absorptiometry. J Hand Surg Am 41(7):767–774
10. Pervaiz K et al (2013) Osteoporosis and shoulder osteoarthritis: incidence, risk factors, and surgical implications. J Shoulder Elb Surg 22(3):e1–8
11. Park SH et al (2020) Opportunistic use of chest CT for screening osteoporosis and predicting the risk of incidental fracture in breast cancer patients: a retrospective longitudinal study. PLoS ONE 15(10):e0240084
12. Courtois EC, Ohnmeiss DD, Guyer RD (2023) Assessing lumbar vertebral bone quality: a methodological evaluation of CT and MRI as alternatives to traditional DEXA. Eur Spine J. (32):3176–3182

13. Roch PJ et al (2023) Combination of vertebral bone quality scores from different magnetic resonance imaging sequences improves prognostic value for the estimation of osteoporosis. Spine J 23(2):305–311
14. Huang W et al (2023) Use of MRI-based vertebral bone quality score (VBQ) of S1 body in bone mineral density assessment for patients with lumbar degenerative diseases. Eur Spine J 32(5):1553–1560
15. Pickhardt PJ et al (2016) Effect of IV contrast on lumbar trabecular attenuation at routine abdominal CT: correlation with DXA and implications for opportunistic osteoporosis screening. Osteoporos Int 27(1):147–152
16. Aynaszyan S et al (2023) Patterns of misdiagnosis and discordance in detecting osteoporosis: a comparison of dual-energy X-ray absorptiometry and lumbar computed Tomography Hounsfield Units. Clin Spine Surg 36(8):E369–e374
17. Choi MK, Kim SM, Lim JK (2016) Diagnostic efficacy of Hounsfield units in spine CT for the assessment of real bone mineral density of degenerative spine: correlation study between T-scores determined by DEXA scan and Hounsfield units from CT. Acta Neurochir (Wien) 158(7):1421–1427
18. Cohen A et al (2021) Opportunistic screening for osteoporosis and osteopenia by routine computed tomography scan: a heterogeneous, multiethnic, middle-eastern population validation study. Eur J Radiol 136:109568
19. Courtois EC et al (2024) Evaluating Alternatives to DEXA for assessing bone quality in patients undergoing spine surgery. J Neurosurg Spine 40(1):84–91
20. Elarjani T et al (2021) Quantifying bone quality using computed Tomography Hounsfield Units in the mid-sagittal view of the lumbar spine. World Neurosurg 151:e418–e425
21. Hendrickson NR et al (2018) *Bone Mineral density T-Scores derived from CT attenuation numbers (Hounsfield Units): clinical utility and correlation with dual-energy X-ray absorptiometry.* Iowa Orthop. 38:25–31
22. Luo X et al (2023) Hounsfield units on abdominal computed tomography: a new tool for predicting osteoporosis. Acta Radiol 64(11):2841–2848
23. Wongsuttilert A et al (2023) Correlation between Hounsfield Units measured by diagnostic noncontrast enhanced CT in Lumbar Spine and femoral Neck with Bone Mineral Density measured by dual-energy X-Ray absorptiometry. Rama Med J 46(2):1–6
24. Yang G et al (2022) Prediction of osteoporosis and osteopenia by routine computed tomography of the lumbar spine in different regions of interest. J Orthop Surg Res 17(1):454
25. Li YL et al (2018) Opportunistic screening for osteoporosis in abdominal computed tomography for Chinese population. Arch Osteoporos 13(1):76
26. Deshpande N et al (2023) Alternatives to DEXA for the assessment of bone density: a systematic review of the literature and future recommendations. J Neurosurg Spine 38(4):436–445
27. Pickhardt PJ et al (2015) Comparison of femoral neck BMD evaluation obtained using Lunar DXA and QCT with asynchronous calibration from CT colonography. J Clin Densitom 18(1):5–12
28. Murata K et al Low hounsfield unit values at sagittal section on computed tomography predicts vertebral fracture following short spinal fusion. J Orthop Sci
29. Li J et al (2023) The preoperative Hounsfield unit value at the position of the future screw insertion is a better predictor of screw loosening than other methods. Eur Radiol 33(3):1526–1536
30. Nakashima D et al (2019) Quantitative CT-based bone strength parameters for the prediction of novel spinal implant stability using resonance frequency analysis: a cadaveric study involving experimental micro-CT and clinical multislice CT. Eur Radiol Exp 3(1):1
31. Kale H, Yadav S (2023) Can routine MRI spine T1 sequences be used for prediction of decreased bone density? Acta Radiol 64(1):164–171
32. Ahern DP et al (2021) A meta-analysis of the diagnostic accuracy of Hounsfield units on computed topography relative to dual-energy X-ray absorptiometry for the diagnosis of osteoporosis in the spine surgery population. Spine J 21(10):1738–1749
33. Gausden EB et al (2017) Opportunistic use of CT imaging for osteoporosis screening and bone density Assessment: a qualitative systematic review. J Bone Joint Surg Am 99(18):1580–1590