Osteoporosis in spine surgery patients: what is the best way to diagnose osteoporosis in this population?

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OBJECTIVE The goal of this study was to compare different recognized definitions of osteoporosis in patients with degenerative lumbar spine pathology undergoing elective spinal fusion surgery to determine which patient population should be considered for preoperative optimization.

METHODS A retrospective review of patients in whom lumbar spine surgery was planned at 2 academic medical centers was performed, and the rate of osteoporosis was compared based on different recognized definitions. Assessments were made based on dual-energy x-ray absorptiometry (DXA), CT Hounsfield units (HU), trabecular bone score (TBS), and fracture risk assessment tool (FRAX). The rate of osteoporosis was compared based on different definitions: 1) the WHO definition (T-score ≤ -2.5) at total hip or spine; 2) CT HU of < 110 ; 3) National Bone Health Alliance (NBHA) guidelines; and 4) "expanded spine" criteria, which includes patients meeting NBHA criteria and/or HU < 110 , and/or "degraded" TBS in the setting of an osteopenic T-score. Inclusion criteria were adult patients with a DXA scan of the total hip and/or spine performed within 1 year and a lumbar spine CT scan within 6 months of the physician visit.

RESULTS Two hundred forty-four patients were included. The mean age was 68.3 years, with 70.5% female, 96.7% Caucasian, and the mean BMI was 28.8. Fracture history was reported in 53.8% of patients. The proportion of patients identified with osteoporosis on DXA, HUs, NBHA guidelines, and the authors' proposed "expanded spine" criteria was 25.4%, 36.5%, 75%, and 81.9%, respectively. Of the patients not identified with osteoporosis on DXA, 31.3% had osteoporosis based on HU, 55.1% had osteoporosis with NBHA, and 70.4% had osteoporosis with expanded spine criteria ($p < 0.05$), with poor correlations among the different assessment tools.

CONCLUSIONS Limitations in the use of DXA T-scores alone to diagnose osteoporosis in patients with lumbar spondylosis has prompted interest in additional methods of evaluating bone health in the spine, such as CT HU, TBS, and FRAX, to inform guidelines that aim to reduce fracture risk. However, no current osteoporosis assessment was developed with a focus on improving outcomes in spinal surgery. Therefore, the authors propose an expanded spine definition for osteoporosis to identify a more comprehensive cohort of patients with potential poor bone health who could be considered for preoperative optimization, although further study is needed to validate these results in terms of clinical outcomes.

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KEYWORDS Hounsfield units; dual-energy x-ray absorptiometry; DXA; osteoporosis; trabecular bone score; Fracture Risk Assessment Tool; FRAX

ABBREVIATIONS BMD = bone mineral density; DXA = dual-energy x-ray absorptiometry; FRAX = Fracture Risk Assessment Tool; HU = Hounsfield unit; LL = lumbar lordosis; MOF = major osteoporotic fracture; NBHA = National Bone Health Alliance; PI = pelvic incidence; TBS = trabecular bone score.

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OSTEOPOROSIS is characterized by low bone mass and poor bone quality leading to fragility fractures and is the most common metabolic bone disease.¹⁻³ In the absence of fragility fractures after the age of 50 years, osteoporosis is classically defined by low bone mineral density (BMD) based on dual-energy x-ray absorptiometry (DXA). The WHO classifies bone health in adults age > 50 years by using the lowest spine or total hip BMD compared to a reference standard taken from young white women. Osteoporosis is defined as a T-score ≤ -2.5 , osteopenia defined with a T-score between -1.0 and -2.4 , and normal bone density with a T-score > -1.0 .⁴ Despite the important role that DXA has played in fracture risk assessment, many individuals with incident fragility fractures have BMD values in the osteopenic range.⁵ Bone quality reflects the collagen structure, mineralization, turnover, and microarchitecture. Bone microarchitecture refers to the shape, orientation, and interconnectedness of trabeculae, and the width, distribution, and porosity of bone, and is more difficult to measure.

The trabecular bone score (TBS) was developed to describe bone microarchitecture of the vertebral body from lumbar spine DXA images. It does this by measuring gray-level texture variations from one pixel to the next across 2D images. This is not a direct measurement of bone microarchitecture but gives TBS the potential to discern differences in 3D microarchitecture between 2D DXA measurements that have similar BMD levels.¹⁻³ Higher values of TBS are obtained in more homogeneously textured bone, whereas heterogeneously textured bone, with higher porosity and/or fatty infiltration, results in lower TBS values. This texture parameter obtained from a TBS provides additional skeletal information that is not captured from the standard BMD measurement, which makes TBS independent of and additive to fracture risk prediction by BMD.^{1-3,6} TBS is typically obtained from reanalysis of anterior-posterior lumbar spine DXA images. Lumbar TBSs are an age-dependent variable with little change observed between the ages of 30 and 45 years. Studies have shown that a progressive decrease which is more marked in women than in men, is observed with advancing age.^{1,8} Given the importance of bone microarchitecture in the evaluation of risk for fragility fractures with advancing age, TBS complements BMD assessment by DXA scan to inform clinical decision-making.⁷

Another method to estimate BMD is the use of Hounsfield unit (HU) measurements from CT.⁹⁻¹² HUs are a dimensionless unit calculated based on the radiodensity of tissue, with increasingly positive values reflecting more dense tissue. Because lumbar CT is a routine preoperative examination for patients being evaluated for spinal surgery, the additional determination of HUs is essentially an opportunistic and costless augmentation to the information routinely obtained from CT scans obtained for any reason. An HU < 110 of the L1 vertebral body has been proposed as a diagnostic threshold for osteoporosis.¹² Additionally, HUs may be particularly useful in patients with degenerative changes in the spine, because cortical sclerosis may increase the measured BMD on DXA,⁹ and has recently been shown to be useful to monitor improvement in lumbar BMD following teriparatide treatment.¹³

Recognizing the limitations in sensitivity of any single diagnostic test for defining osteoporosis, imaging modalities have been combined with clinical risk factors to improve diagnostic sensitivity. These assessments are particularly important for spine surgeons, because DXA has been demonstrated to be an inadequate predictor of osteoporosis-related complications following elective spinal fusion surgery.^{14,15} The most commonly used combined modality is the Fracture Risk Assessment Tool (FRAX), which estimates the 10-year probability of hip fracture and major osteoporotic fractures (MOFs) based on the individual's risk factors profile.^{3,16} FRAX may be determined with or without BMD data and can be used to identify patients who need formal DXA screening and to aid treatment decisions. More recently, TBS has been used to further refine the FRAX predictive capabilities.¹

With the development of multiple assessment tools for bone health, various definitions of osteoporosis have been established. In addition to the WHO criteria, the National Bone Health Alliance (NBHA) defined osteoporosis based on the presence of any of the following 3 criteria: "T-score ≤ -2.5 at the hip or spine, history of low energy hip fracture, clinical (i.e. diagnosed, not incidentally identified on imaging), vertebral, proximal humerus, pelvis, or some distal forearm fractures, or FRAX scores with $\geq 3\%$ (hip) or $\geq 20\%$ (major) 10-year fracture risk."¹⁷ Using the expanded NBHA definition, compared to the WHO definition, would increase the prevalence of osteoporosis in the United States population ≥ 50 years old, to 30% of women and 16% of men.¹⁸ Thus, as with all disease, the method used to define it determines its prevalence and management.

We hypothesized that there is substantial variability in bone health characterization in patients with degenerative lumbar spine pathology based on different methods for diagnosing osteoporosis. Therefore, the objectives of this study were as follows: 1) to compare the performance of indicators of bone health developed for fracture risk assessment in patients with degenerative spinal disorders indicated for elective surgical intervention, and 2) to propose criteria for diagnosing osteoporosis in this patient population to identify those who should be considered for preoperative bone health optimization, to minimize the risk of surgical complications.

Methods

Following institutional review board approval, a retrospective review of patients from 2 independent academic centers was performed. All patients were evaluated for and/or underwent elective surgical treatment of lumbar degenerative pathology between 2007 and 2018. The additional inclusion criteria were patients with a DXA scan of the hips and/or spine performed within 1 year and CT scans within 6 months of the surgeon's evaluation. Patients were excluded if they were younger than 18 years or had a concurrent infection, trauma, malignancy, skeletal dysplasia, neuromuscular disorders, or concomitant or staged anterior-posterior procedure.

Baseline characteristics, medical comorbidities, and surgical data were obtained from the electronic medical record. Patients were classified as having a fracture if

TABLE 1. Osteoporosis cohort and group definition

Group	Definition
1	WHO classic definition, lowest total hip or spine T-score ≤ -2.5
2	L1 vertebral body HU < 110
3	NBHA definition (at least 1 of the following 3 criteria met): a) T-score ≤ -2.5 at the hip or spine, or; b) history of low-energy hip fracture, clinical vertebral (i.e., diagnosed, not incidentally identified on imaging), proximal humerus, pelvis, or some distal forearm fractures, or; c) FRAX (calculated with BMD) indicating a $\geq 3\%$ (hip) or $\geq 20\%$ (MOF) 10-yr fracture risk
4	Proposed “expanded spine” definition (at least 1 of the 3 criteria met): a) NBHA definition, or; b) HU < 110 , or; c) osteopenia (lowest T-score between -1.0 and -2.4) as well as “degraded” TBS (< 1.2)

there was a documented history of a fragility fracture. Prior CT scans obtained during patient workup were used to calculate the HU of a defined region of interest in the first lumbar vertebral body, as previously described.¹³ There were multiple CT scanners, with a 120-kV tube voltage. HU measurements were excluded from analysis if there was prior instrumentation at L1. All measurements were made using the institutions’ standard Picture Archiving and Communication Software (PACS). BMD by DXA was determined by using the lowest available T-scores of the total hip and lumbar spine. The FRAX 10-year MOF and hip fracture risk incorporating DXA BMD were documented from the medical record or calculated using the FRAX risk assessment calculator.¹⁹ The mean TBSs of L1–4 were calculated using TBS iNsight (TBS iNsight (Osteo), version 3.0.2.0; Medimaps Group). TBS ≤ 1.2 was considered degraded microarchitecture, TBS between 1.2 and 1.35 was partially degraded microarchitecture, and TBS ≥ 1.35 was normal.^{20,21}

We then independently applied the following 4 diagnostic criteria to the entire study cohort to determine the prevalence of osteoporosis based on each definition (Table 1). Group 1) WHO—lowest total hip or spine T-score ≤ -2.5 . Group 2) L1 vertebral body HU < 110 . Group 3) NBHA—at least 1 of the following 3 criteria met: a) T-score ≤ -2.5 at the hip or spine; or b) history of low-energy hip fracture, clinical vertebral (i.e., diagnosed, not incidentally identified on imaging), proximal humerus, pelvis, or some distal forearm fractures; or c) FRAX (calculated with BMD) indicating a $\geq 3\%$ (hip) or $\geq 20\%$ (MOF) 10-year fracture risk. Group 4) Proposed “expanded spine” criteria—at least 1 of the 3 criteria met: a) NBHA definition; or b) HU < 110 ; or c) osteopenia (lowest T-score between -1.0 and -2.4) as well as “degraded” TBS (< 1.2).

Statistical Analysis

Standard descriptive summary statistics (e.g., means

TABLE 2. Baseline demographic data in 244 patients with osteoporosis who underwent spine surgery

Characteristic	Value (%)
Mean age in yrs, $\pm$ SD	68.3 $\pm$ 9.2
Age group, no. (%)	
<60 yrs	38 (15.6)
60–70 yrs	103 (42.2)
>70 yrs	103 (42.2)
Sex, no. (%)	
Female	172 (70.5)
Ethnicity, no. (%)	
Asian	2 (0.8)
Latino	2 (0.8)
Native American	1 (0.4)
Unknown	3 (1.2)
White	236 (96.7)
BMI, mean $\pm$ SD	28.8 $\pm$ 5.9
Fracture history, no. (%)	
None	48 (46.2)
<50 yrs old	19 (18.3)
≥ 50 yrs old	25 (24.0)
Both	12 (11.5)

and SDs for continuous variables and percentage for categorical variables) were used to summarize demographic variables. Comparisons of categorical variables between subgroups were made using the chi-square test or the Fisher exact test, depending on the normality of the sample. Comparisons of continuous variables were completed using independent t-tests or simple linear regression. Alpha was set at a significance level of $p < 0.05$. Statistical analysis was performed using JMP software (version 14.1.0., 1989–2019; SAS Institute, Inc.).

Results

For the 244 patients included in the study, the mean age was 68.3 years, 70.5% were female, and 96.7% were white, with a mean BMI of 28.8 (Table 2). More than 53.8% reported a history of fracture, with 24% occurring after the age of 50 years.

Overall Densitometric Characteristics

Based on the lowest BMD of hip or spine, the overall mean (SD) DXA T-score was -1.72 (1.11). Based on WHO criteria there were 62 (25.4%) patients with osteoporosis, 132 (54.1%) patients with osteopenia, and 50 (20.5%) patients with normal BMD (Table 3). The mean FRAX 10-year risk of MOF was 17.9% (9.7%) and the mean hip fracture risk was 5.4% (5.4%) (Table 3). The mean TBS was 1.31 (0.12). There were 33 (22.3%) patients with normal TBS, 79 (53.4%) with partially degraded, and 36 (24.3%) with degraded TBS. The mean L1 HU was 131.7 (44.7). There were 53 (36.5%) of patients with HU < 110 , and 38 (26.2%) of patients with HU ≥ 160 .

TABLE 3. Overall distribution of bone health measurements in 244 patients with osteoporosis who underwent spine surgery

Measurement	Value (%)
DXA T-score, no. (%) [*]	
Normal	50 (20.5)
Osteopenia	132 (54.1)
Osteoporosis	62 (25.4)
Mean T-score, $\pm$ SD	-1.72 ± 1.11
HU, no. (%)	
<110	53 (36.5)
≥ 110	92 (63.5)
<160	107 (73.8)
≥ 160	38 (26.2)
Mean HU, $\pm$ SD	131.7 ± 44.7
TBS, no. (%)	
Intact	33 (22.3)
Partially degraded	79 (53.4)
Degraded	36 (24.3)
Mean TBS, $\pm$ SD	1.31 ± 0.12
Mean % w/ FRAX MOF, $\pm$ SD [†]	17.9 ± 9.7
Mean % w/ FRAX hip fracture, $\pm$ SD [†]	5.4 ± 5.4

^{*} Based on lowest T-score on DXA measurements of hip or spine.

[†] 10-year fracture risk.

Comparisons of Densitometric Characteristics

The proportion of patients identified with osteoporosis on WHO criteria, HU, NBHA, and expanded spine criteria was 25.4%, 36.5%, 75%, and 81.9%, respectively ($p < 0.0001$) (Table 4). In patients without WHO classification of osteoporosis based on T-score ≤ -2.5 , 31.3% had osteoporosis based on HU, 55.1% using NBHA criteria, and 70.4% had osteoporosis with expanded spine criteria (Table 4).

To examine the influence of age and sex, the groups were further stratified. Among women less than 60 and women 60–70 years old, the rates of osteoporosis diagnosis using DXA, HU, and NBHA definitions were comparable (Fig. 1). However, there was an increase in osteopenia diagnosis using the HU definition for women greater

FIG. 1. Age-specific and sex-specific proportion of patients with osteoporosis, based on the different definitions of osteoporosis.

than 70 years old (63% vs 36% for both DXA and NBHA definitions). Notably, the diagnosis of osteoporosis among men less than 60 years old was higher among the DXA- and NBHA-defined groups (29%) versus the HU-defined group (17%), whereas the diagnosis of osteoporosis in men greater than 70 years old was higher among the HU group (46%) than either the DXA or NBHA groups (6%).

The association between DXA, HUs, and TBS was evaluated with simple linear regression (Fig. 2). The association between T-score and CT HU was weak, with $R^2 = 0.22$ ($p < 0.0001$), and, as expected, TBS and T-score were weakly correlated consistent with each being independent indicators of bone strength, with $R^2 = 0.10$ ($p = 0.0001$). There were also weak correlations between osteoporosis based on WHO class definition and osteoporosis based on the other 3 definitions that were examined (Table 5).

Representative Case

A 65-year-old woman with a history of a prior L4–5 instrumented posterolateral fusion 4 years prior was referred with increasing back pain and progressive forward-leaning posture. She had a grade II spondylolisthesis and clear pseudarthrosis with loosening of the pedicle screws at L4 and L5. On standing radiographs (EOS Imaging), she had a sagittal vertical axis of 16 cm, pelvic incidence (PI) 70°, pelvic tilt 29°, and lumbar lordosis (LL) 35°, with

TABLE 4. Comparison of distribution of bone quality measurements grouped by T-score

DXA T-Score [*]	HU, No. (%)			NBHA, No. (%)			Expanded Spine, No. (%)		
	Non-OPS	OPS	p Value	Non-OPS	OPS	p Value	Non-OPS	OPS	p Value
Normal	38 (90.5)	4 (9.5)	<0.0001	16 (88.9)	2 (11.1)	<0.0001	14 (70)	6 (30.0)	<0.0001
Osteopenia	50 (58.1)	36 (41.9)		19 (31.7)	41 (68.3)		15 (19.2)	63 (80.8)	
Osteoporosis	4 (23.5)	13 (76.5)		0 (0)	62 (100)		0 (0)	62 (100)	
Total	92 (63.5)	53 (36.5)		35 (25)	105 (75)		29 (18.1)	131 (81.9)	

OPS = osteoporosis.

Boxed values—patients without OPS based on T-score: 31.3% had OPS on HU, 55.1% had OPS with NBHA, and 70.4% had OPS with expanded spine criteria. Significant results ($p < 0.05$) are written in boldface type.

^{*} Lowest T-score based on DXA measurements.

FIG. 2. Scatterplots demonstrating poor correlation between (A) HUs and T-score, (B) TBS and HUs, and (C) TBS and T-score.

only 12° of lordosis from L4 to S1 (Fig. 3A) and PI–LL mismatch of 35°. Her preoperative DXA demonstrated a T-score –0.4 at the total hip, nondiagnostic spine, and TBS 1.43. She underwent removal of posterior hardware at L4–5, and then received L4–5 and L5–S1 anterior lumbar interbody fusions, followed by posterior instrumented fusion for L2–sacrum with S2–alar–iliac supplemental fixation, resulting in 61° of lumbar lordosis, and 40° of lumbar lordosis from L4 to S1 (Fig. 3B). However, several weeks postoperatively she developed mechanical back pain and a progressive forward-leaning posture, with difficulty ambulating due to intractable pain. She was found to have proximal junctional failure with a fracture through the bilateral L2 pedicles (Fig. 3C and D). She then required extension of her construct to T10 (Fig. 3E). In retrospect, the HU measurement at the level of the L2 pedicles was 68 (Fig. 3F), which is suggestive of severe osteoporosis despite a normal total hip T-score and normal vertebral body TBS.

Discussion

Osteoporosis as classically defined by T-score and/or low-energy fracture after the age of 50 years has been associated with adverse outcomes in spine surgery including screw loosening, pseudarthrosis, proximal and distal junctional fracture, or kyphosis.^{22–24} Osteoanabolic medications used both before and after surgery have been shown to improve outcomes of spine surgery in osteoporotic patients. Thus, the importance of preoperative evaluation of bone health is clear, although the optimal method to identify patients at risk of poor surgical outcomes is not known.²³

The overall rate of osteoporosis regardless of definition was high in our patients being evaluated for possible spine surgery. The average T-score in our sample was –1.72, and 25.4% of patients were identified with osteoporosis based on DXA alone. However, each of the additional criteria identified a greater proportion of patients who may be considered as having poor bone health. We found that based on HU, NBHA guidelines, and our proposed expanded spine criteria, 36.5%, 75%, and 81.9% of patients, respectively, had poor bone health. Importantly, this means that based on these additional assessments or criteria, significantly more patients were identified with poor bone health if surgical outcomes rather than fracture risk was the basis

for diagnosis, despite a T-score that would otherwise have not indicated osteoporosis.

Although we identified a greater proportion of patients with potential poor bone health, these results mirror a prior study on patients undergoing primary lumbar fusion surgery, in which 10% were diagnosed with osteoporosis and 59% were diagnosed with osteopenia. However, there was still a 33% risk of osteoporosis-related complications in the osteopenia group, whereas the osteoporotic group had a 50% risk.²⁵ In a separate study on postmenopausal women undergoing spinal fusion surgery, CT postprocessing techniques were used to calculate vertebral trabecular BMD, and finite-element analysis was used to predict fracture and fragile bone strength. Whereas only 14% of the cohort had osteoporosis based on BMD alone, 27% had fragile bone strength, and 29% had poor bone quality based on finite-element analysis, suggesting that additional parameters outside of BMD result in poor bone health.²⁶

Although DXA T-scores have been the gold standard for assessing bone health,²⁷ this method may overestimate spine BMD in the setting of changes related to lumbar spondylosis thereby limiting their utility in this region of interest.^{9,28} This has led to growing interest in alternative or supplemental methods of assessing bone quality,^{9,11,28} especially in the setting of hyperparathyroidism, morbid obesity, single vertebral reading, or anatomical variation.²⁹ Additionally, Z-scores rather than T-scores are used when assessing BMD in children, men younger than age 50 years, and premenopausal women.²⁹ These types of limitations have led to methods that may be less affected by degenerative changes in the spine caused by comorbidities.^{9,30}

Opportunistic use of screening CT scans by measuring HU isolates regions of interest to the vertebral body (or even pedicle screw tracts), thus potentially being use-

TABLE 5. Group comparison using the Pearson chi-square test

Comparison	R ²	Chi-Square Test	p Value
WHO by HU	0.0001	0.028	0.8678
WHO by NBHA	0.4332	87.520	<0.0001
WHO by expanded spine	0.2886	51.544	<0.0001

Significant results (p < 0.05) are written in boldface type.

FIG. 3. Representative case demonstrating utility of broader bone health screening. (A) Standing lateral radiograph demonstrating sagittal vertical axis 16 cm and 35° PI-LL mismatch. (B) Postoperative lateral lumbar spine radiograph demonstrating L2–S1 construct with pelvic supplemental fixation and restoration of lumbar lordosis. Sagittal CT demonstrating (C) right and (D) left pedicles with fracture extending through both pedicles and superior vertebral body. (E) Postoperative lateral standing scoliosis radiograph obtained following revision with extension up to T10. (F) HU measurement of 68 in the L2 vertebral body at the level of the pedicles.

ful in place of DXA in degenerative and deformity lumbar spine cases.^{9,10,13} In the lumbar spine, HU < 110 has been identified as a cutoff or threshold for the diagnosis of osteoporosis.^{30,31} Although 25.4% of patients had osteoporosis based on DXA alone, applying the HU threshold of < 110 identified that 36.5% of patients had osteoporosis. Because many spine patients have significant degenerative changes or spinal deformity with invalid lumbar BMD measurements on DXA,³² HU measurements are a valuable tool in the lumbar spine, and may provide a superior assessment of risk for vertebral fracture.³³ For instance, HU measurements ≤ 90 at L1 resulted in a significantly increased risk of fracture.³⁴

TBS informs fracture prediction and is less affected by degenerative changes than is BMD. Because TBS is independent of BMD,²⁸ the addition of TBS analysis aids in stratifying fracture risk, even in the presence of normal DXA T-scores. For instance, in a cadaveric study, there was a significant correlation between TBS and trabecular bone volume, but no correlation between TBS and BMD.³⁵ We found that 24.3% of patients had “degraded” bone microarchitecture on TBS, including 17.1% of patients without osteoporosis based on DXA T-scores alone, thus identifying additional patients who may be at risk of osteoporosis-related complications postoperatively. We similarly found that BMD based on DXA was poorly correlated with the other assessment definitions as well as TBS. This was also consistent with prior findings that BMD measures bone quantity, whereas TBS may be more reflective of bone porosity and/or fatty infiltration.⁷ Patients with type 2 diabetes often do not have diminished BMD but have elevated fracture risk associated with low TBS.⁷ The TBS can also be used as an input to FRAX and aid identification of high fracture risk. However, whereas TBS has been found to be associated with an overall increased fracture risk,^{28,36,37} its clinical performance in predicting complications following spine surgery in the setting of degenerative changes, prior surgery, or spinal deformity has yet to be fully determined.

Based on our data, there was a high rate of poor bone

health in patients undergoing elective lumbar spine surgery, with 25.4% of patients diagnosed by T-score alone, and 81.9% with osteoporosis if defined by our proposed expanded spine criteria. Because there is an elevated risk of postoperative complications in both osteoporotic and osteopenic patients (as defined by T-score) undergoing elective lumbar spine surgery,³⁸ we recommend that preoperative testing with DXA be supplemented by opportunistic CT imaging for HU measurements. We also propose using the expanded spine criteria to identify the broadest cohort of patients who should be considered for medical optimization of bone health prior to surgery, although further clinical outcome studies are required to validate the use of our proposed criteria.

There are limitations to this study, such as its retrospective nature and moderate sample size. For instance, there was incomplete fracture history data on some of the patients, so it was not possible to correlate fracture risk with the different osteoporosis definitions, and further assessment of future fracture risk would allow us to establish the sensitivity and specificity of each definition. There was potential selection bias in who underwent DXA because the use was not universally applied. Additionally, because clinical outcome endpoints such as fusion rate or hardware failure were not assessed, it is not possible to validate our proposed expanded spine criteria to stratify postoperative risk. Also, there may be variability in the HU assessments based on differences in CT machines and distance in collimator from the patient. Last, we used T-scores for all patients in this study, although Z-scores would be the more appropriate measure in patients < 50 years of age. Although the expanded spine criteria is complicated, and may be challenging to implement in everyday use, the model was designed to be comprehensive. Further studies could examine a “modified spine criteria” by using DXA with HU and FRAX as a screening method. This would provide a simpler model that could readily be used by most spine surgeons, and would be likely to identify a majority of patients with osteoporosis.

Conclusions

Although DXA has been the historical gold standard in assessing bone health, it has significant limitations in patients with lumbar spondylosis, which has prompted spine surgeons to seek additional methods of evaluating bone health in the spine, such as CT HU, TBS, and FRAX. Even newer diagnostic criteria for osteoporosis, such as the NBHA guidelines, remain focused on predicting fracture risk. Therefore, we propose expanded spine criteria to identify patients at risk of poor surgical outcomes due to poor bone health or “surgical osteoporosis” despite “non-osteoporotic” T-scores. These criteria identified that 81.9% of our patients had poor bone health, including 70.4% of patients with a T-score > -2.5. The expanded spine criteria could aid in the identification of patients with poor health to facilitate bone health optimization prior to spine surgical intervention, although further study is needed to validate these results with clinical outcomes.

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