Prevalence of osteoporosis and osteopenia diagnosed using quantitative CT in 296 consecutive lumbar fusion patients

Brandon B. Carlson, MD, MPH,¹ Stephan N. Salzmann, MD,² Toshiyuki Shirahata, MD, PhD,² Courtney Ortiz Miller, BA,² John A. Carrino, MD, MPH,³ Jingyan Yang, MHS, DrPH,^{2,4} Marie-Jacqueline Reisener, MD,² Andrew A. Sama, MD,² Frank P. Cammisa, MD,² Federico P. Girardi, MD,² and Alexander P. Hughes, MD²

¹Marc A. Asher, MD, Comprehensive Spine Center, University of Kansas Medical Center, Kansas City, Kansas; ²Spine Care Institute and ³Department of Radiology and Imaging, Hospital for Special Surgery, New York; and ⁴Department of Epidemiology, Mailman School of Public Health, Columbia University, New York, New York

OBJECTIVE Osteoporosis is a metabolic bone disease that increases the risk for fragility fractures. Screening and diagnosis can be achieved by measuring bone mineral density (BMD) using quantitative CT tomography (QCT) in the lumbar spine. QCT-derived BMD measurements can be used to diagnose osteopenia or osteoporosis based on American College of Radiology (ACR) thresholds. Many reports exist regarding the disease prevalence in asymptomatic and disease-specific populations; however, osteoporosis/osteopenia prevalence rates in lumbar spine fusion patients without fracture have not been reported. The purpose of this study was to define osteoporosis and osteopenia prevalence in lumbar fusion patients using QCT.

METHODS A retrospective review of prospective data was performed. All patients undergoing lumbar fusion surgery who had preoperative fine-cut CT scans were eligible. QCT-derived BMD measurements were performed at L1 and L2. The L1–L2 average BMD was used to classify patients as having normal findings, osteopenia, or osteoporosis based on ACR criteria. Disease prevalence was calculated. Subgroup analyses based on age, sex, ethnicity, and history of abnormal BMD were performed. Differences between categorical groups were calculated with Fisher's exact test.

RESULTS Overall, 296 consecutive patients (55.4% female) were studied. The mean age was 63 years (range 21–89 years). There were 248 (83.8%) patients with ages ≥ 50 years. No previous clinical history of abnormal BMD was seen in 212 (71.6%) patients. Osteopenia was present in 129 (43.6%) patients and osteoporosis in 44 (14.9%). There were no prevalence differences between sex or race. Patients ≥ 50 years of age had a significantly higher frequency of osteopenia/osteoporosis than those who were < 50 years of age.

CONCLUSIONS In 296 consecutive patients undergoing lumbar fusion surgery, the prevalence of osteoporosis was 14.9% and that for osteopenia was 43.6% diagnosed by QCT. This is the first report of osteoporosis disease prevalence in lumbar fusion patients without vertebral fragility fractures diagnosed by QCT.

<https://thejns.org/doi/abs/10.3171/2020.5.FOCUS20241>

KEYWORDS osteoporosis; osteopenia; quantitative computed tomography; QCT; bone mineral density; disease prevalence; degenerative lumbar disease

OSTEOPOROSIS is a disease of living bone tissue that results in generalized skeletal fragility in which both bone density and quality are sufficiently weak that fractures may occur with minimal trauma.¹ Under normal developmental conditions, peak bone mass is acquired at the end of skeletal maturation.^{1,2} Males develop larger bone size and cortical thickness due to a prolonged

maturation period compared to females; however, volumetric trabecular density is similar between sexes.² Peak bone mass is an important reference point, after which a combination of genetic, physical, hormonal, and nutritional factors decrease bone mass throughout life. As bone mass declines, fracture risks increase; this is the basis for diagnosing osteoporosis.

ABBREVIATIONS ACR = American College of Radiology; BMD = bone mineral density; DXA = dual-energy x-ray absorptiometry; HR-MRI = high-resolution MRI; HR-pQCT = high-resolution peripheral QCT; QCT = quantitative CT; WHO = World Health Organization.

SUBMITTED March 23, 2020. **ACCEPTED** May 13, 2020.

INCLUDE WHEN CITING DOI: 10.3171/2020.5.FOCUS20241.

Fragility fractures occur when bone density and quality decline to a point where minimal trauma results in bone failure and fracture. The most common fragility fractures occur at the proximal femur, wrist, humerus, and vertebral bodies.^{1,3} The occurrence of one or more low-trauma fractures is sufficient for diagnosing osteoporosis clinically.⁴ Historically, this was the only method for identifying and treating patients with metabolic bone disease. With radiological advancements, earlier osteoporosis diagnosis and intervention are now possible.

Osteoporosis can be diagnosed radiographically/radiologically using plain radiography, dual-energy x-ray absorptiometry (DXA), volumetric quantitative CT (QCT), high-resolution MRI (HR-MRI), and high-resolution peripheral QCT (HR-pQCT).¹ DXA was first described in 1963 by Cameron and Sorenson⁵ and is still widely used to assess bone mineral density (BMD).^{6–10} The World Health Organization (WHO) diagnostic criteria for osteoporosis and osteopenia developed in 1994 are based on DXA areal BMD (g/cm^2) measurements and estimate the future fracture risk.¹¹ DXA has variable measurement reliability at different skeletal sites and there is controversy regarding its accuracy in the lumbar spine. Due to the 2D nature of DXA imaging, factors such as metallic foreign bodies or implants, sclerotic bone from degenerative changes,¹² coronal or sagittal deformities, aortic calcifications,¹³ and obesity¹⁴ may confound measurements and overestimate BMD in the lumbar spine. The WHO and International Osteoporosis Foundation now recommend only using femoral neck measurements for diagnosing osteoporosis with DXA due to these known limitations.^{15–17}

QCT is an alternative BMD measurement method used in the lumbar spine. First described by Regsegger et al. in 1974¹⁸ and later refined by Cann and Genant in 1980¹⁹ and Cann in 1988,²⁰ QCT is performed using a standard CT scanner with a calibration phantom under the patient, allowing density measurements (in Hounsfield units) to be converted to BMD. Newer scanners and software enhancements can provide phantomless conversions. QCT quantifies volumetric BMD as milligrams of hydroxyapatite per cubic centimeter (mg/cm^3) of trabecular and/or cortical bone, depending on the selected region of interest.^{20,21} In the lumbar spine, QCT has less susceptibility to degenerative changes and aortic calcifications and is more sensitive to changes in trabecular bone density compared to DXA.^{22–25} QCT-based BMD evaluation for osteoporosis diagnosis was first described in 2008.

Similar to DXA, QCT-measured BMD can be used to assess future fracture risk, and thus diagnose osteoporosis. The International Society for Clinical Densitometry recommends measuring the average BMD of L1 and L2.²⁶ The average L1–2 BMD is the standard measurement reported on QCT examinations. In 2008, the American College of Radiology (ACR) defined diagnostic thresholds as normal ($> 120 \text{ mg}/\text{cm}^3$), osteopenia ($120 \geq \text{BMD} \geq 80 \text{ mg}/\text{cm}^3$) and osteoporosis ($\text{BMD} < 80 \text{ mg}/\text{cm}^3$) for average L1–2 trabecular bone QCT measurements.²⁷ These thresholds have remained in place since their introduction and are the gold standard for diagnosing osteopenia or osteoporosis using QCT in the lumbar spine.

Patients with degenerative lumbar spinal conditions may have CT performed as part of their diagnostic or pre-

surgical regimen. In these scenarios, the same CT scan can be used to measure BMD and screen for osteoporosis with QCT scans. Clinicians providing spinal care who obtain lumbar spine CT scans have a tremendous opportunity to diagnose abnormal BMD and intervene early; however, there is a paucity of literature published defining the prevalence of osteopenia or osteoporosis diagnosed by QCT in the lumbar spine in patients without vertebral fractures.

The purpose of this study was to report the prevalence of osteopenia and osteoporosis in patients with degenerative conditions undergoing lumbar spinal fusion surgery.

Methods

After obtaining institutional review board approval, we performed a review of prospectively collected clinical data. All patients presenting with degenerative lumbar spinal conditions treated surgically at a single, academic institution between 2014 and 2017 were eligible. For inclusion in the present study, patients must have had a preoperative fine-cut lumbar CT scan, including axial slices at L1 and L2. Patients without CT scans or missing slices at L1 or L2 were excluded.

QCT measurements were performed using Mindways QCT Pro software (Mindways Software, Inc.). Three blinded investigators not involved in patient care performed standardized QCT measurements at L1 and L2 using anonymized studies. The region of interest selection process used has been described in detail in prior studies.^{19,28} In short, an elliptical region of interest was placed exclusively over the trabecular portion of the central vertebral body (Fig. 1). The BMD of the selected region was then calculated using a validated method called asynchronous QCT. In contrast to conventional QCT, asynchronous QCT does not require the presence of a calibration phantom during the patient scan. Instead quality assurance scans are obtained independently from the patient scan. This then allows the conversion of Hounsfield units acquired from the patient scan to BMD estimates in mg/cm^3 .²⁹ Demographic information including age, sex, ethnicity, previous diagnosis of osteopenia or osteoporosis, and surgical levels were collected.

The average L1–2 BMD (mg/cm^3) was calculated for each patient. Patients were categorized according to ACR criteria as being normal (> 120), having osteopenia ($120 \geq \text{BMD} \geq 80 \text{ mg}/\text{cm}^3$) or having osteoporosis ($\text{BMD} < 80 \text{ mg}/\text{cm}^3$).²⁷ Disease prevalence was calculated as the number of patients with a disease state divided by the total population number. Subgroup analyses based on age, sex, race, and patients not previously diagnosed with osteopenia/osteoporosis were also performed. Continuous variables were tested for normality using the Kolmogorov-Smirnov test. Parametric statistical tests were used for comparing continuous variables. Differences in frequency distribution between groups were calculated with Fisher's exact test. Significance was defined as $p < 0.05$. Mean values are presented $\pm$ SD.

Results

Overall, 296 consecutive patients (55.4% female) un-

FIG. 1. Example of QCT scan measurement of volumetric BMD at L1 (left) and L2 (right). The red lines show where on the coronal (lower images) the axial slice is taken (upper images). The red ovals are the measurement region of interest (ROI), and the yellow box shows the user in the measurement software what portion of the vertebral body is being measured by selecting the oval ROI.

dergoing primary lumbar fusion procedures were studied. The mean age was 63 years (range 21–89 years). There were 248 (83.8%) patients with age ≥ 50 years. The cohort was 88.5% Caucasian, 3.7% African American, and 7.8% other. There were 212 (71.6%) patients with no clinical history of abnormal BMD. All patients had nondeformity degenerative spinal conditions and had spinal fusion performed in the lumbar and/or lumbosacral spine from L1 to S1. The number of levels fused were as follows: 1 level ($n = 157$), 2 levels ($n = 98$), 3 levels ($n = 30$), 4 levels ($n = 8$), and 5 levels ($n = 3$).

All patients had preoperative fine-cut CT scans acquired, including L1 and L2. The mean L1–2 BMD measurement for the entire cohort was $118 \text{ mg/cm}^3 \pm 37.8$. Using ACR criteria, patients were diagnosed as: normal, $n = 123$ (41.5%); having osteopenia, $n = 129$ (43.6%); and having osteoporosis, $n = 44$ (14.9%) (Table 1). There were no prevalence differences based on sex or race ($p > 0.05$) (Table 2). Patients 50 years or older ($n = 248$: 48.8% with osteopenia, 17.7% with osteoporosis) had significantly higher disease prevalence than patients younger than 50 years ($n = 48$: 16.7% with osteopenia, 0% with osteoporosis), ($p < 0.0001$) (Table 2). Within the subgroup of 212 patients with no history of disease, 83 (39.2%) had osteopenia and 22 (10.4%) had osteoporosis. There were no lumbar fragility fractures identified in any patient.

Discussion

There are approximately 200 million people worldwide with osteoporosis.^{30,31} A recent report utilized the Nation-

TABLE 1. BMD measurements in 296 consecutive lumbar spine fusion patients measured by QCT and classified by the ACR diagnostic criteria

Normal	Osteopenia	Osteoporosis
$>120 \text{ mg/cm}^3$	$80 \text{ mg/cm}^3 \leq \text{BMD} \leq 120 \text{ mg/cm}^3$	$<80 \text{ mg/cm}^3$
123 (41.5%)	129 (43.6%)	44 (14.9%)

al Health and Nutrition Examination Survey 2010 data to estimate that 53.6 million Americans over 50 years old had low BMD and 10.2 million had osteoporosis.³² As the population ages and the expected life span increases, the prevalence of osteoporosis continues to rise. Monitoring bone health and performing appropriate screening allows for early recognition and intervention, potentially reducing morbidity and mortality rates and healthcare costs.

Vertebral and hip fragility fractures are the primary causes of patient morbidity, mortality, and healthcare-related expenditures resulting from osteoporosis. It is estimated that by 2050, the worldwide incidence of fragility fractures will increase 310% in men and 240% in women compared to 1990 rates.³³ These alarming increases pose a major public health concern and justify the need for better screening and early identification during healthcare encounters.

Osteoporosis is a metabolic bone disease primarily treated by primary care or endocrinology physicians and is often only identified after a fragility fracture. Elderly patients seeking care for other musculoskeletal complaints could be screened and low BMD may be identified before a fracture occurs. Spinal surgeons remain less knowledgeable about screening, treatment, and follow-up of osteoporosis. This trend is seen even in patients with fragility fractures, which should increase clinical suspicion. Multiple studies have suggested algorithms to combat this phenomenon.^{34–39}

Although osteoporosis rates are now at pandemic proportions, few studies exist in the orthopedic and neurosurgical literature describing osteoporosis prevalence based on BMD measurements in patients presenting with musculoskeletal complaints other than fracture. One study of 500 general orthopedic outpatients whose mean age was 67 years quantified BMD with calcaneal quantitative ultrasound and found that 31% had abnormal BMD.⁴⁰ In the orthopedic trauma literature, 260 consecutive patients screened using calcaneal ultrasound identified 30% at high risk for osteoporosis and 21% at moderate risk.³⁴ The largest body of existing literature quantifying osteoporosis prevalence in orthopedic patients is from hip and knee arthroplasty cohorts. Six studies quantified BMD by DXA and reported that the prevalence of osteoporosis ranged from 20.7% to 31% and that that of osteopenia ranged from 37.9% to 45%.^{41–46} In the shoulder and elbow literature, one study reported on 230 patients with DXA-derived BMD, and 12.2% were found to be osteoporotic and 43.6% osteopenic. Among the patients with osteoporosis, 75% were newly diagnosed at presentation.⁴⁷ While not directly an “orthopedic” or “neurosurgical” population, one systematic review paper was identified that synthesized

TABLE 2. Subgroup analyses of lumbar spine fusion patients diagnosed with osteopenia or osteoporosis using lumbar spine QCT measurements

Sex Subgroups			
Diagnosis	Male (n = 132)	Female (n = 164)	
Osteopenia	40.20%	46.30%	
Osteoporosis	15.90%	14%	
Age Subgroups			
Diagnosis	<50 yrs (n = 48)	>50 yrs (n = 248)	
Osteopenia	16.7%*	48.8%*	
Osteoporosis	0%*	17.70%*	
Race Subgroups			
Diagnosis	Caucasian (n = 262)	African American (n = 11)	Other (n = 23)
Osteopenia	115	5	9
Osteoporosis	41	0	3

* $p < 0.0001$.

results of 21 studies reporting osteoporosis prevalence in patients with psoriatic arthritis from 1.4% to 68.8%.⁴⁸

We identified many studies reporting osteoporosis rates in spine patients presenting with vertebral fractures.^{49–56} However, there are very few studies in nonfracture spine patients. Wagner et al. examined 143 patients undergoing single-level lumbar fusions and analyzed CT-derived lumbar BMD with Hounsfield units to further define thresholds that may define DXA-diagnosed osteoporosis or osteopenia in the same patients.⁵⁷ Their results are somewhat limited, given only 36% of osteoporosis patients and 18.4% of osteopenia patients had DXA information for analyses and confirmation of Hounsfield unit thresholds for diagnosis. Another related study by Kohan et al. analyzed 43 adult spinal deformity patients with CT-derived Hounsfield unit measurements in the lumbar spine and DXA using Wagner et al.'s previously described Hounsfield unit thresholds for diagnosis.^{57,58} Their conclusion was that lumbar spine Hounsfield unit measurements are not an appropriate surrogate for BMD measurements in spinal deformity patients. Both of these papers utilize Hounsfield units, not QCT. There can be significant variations in Hounsfield unit measurements between scanner models and/or tube voltage.^{59,60} Wang et al. studied 504 ankylosing spondylitis patients with DXA-measured BMD and reported that 9.7% had osteoporosis and 57.5% had osteopenia.⁶¹ Two studies attempted to further define the relationship between degenerative changes and BMD in the lumbar spine and both found an inverse relationship, indicating that, as spondylosis or disc degeneration increases, BMD decreases.^{62,63} Unfortunately, both studies reported BMD raw values and not osteoporosis/osteopenia rates. Similarly, Yu et al. studied differences in BMD between QCT and DXA in patients with degenerative spinal conditions and concluded that QCT or midlateral DXA is the most accurate BMD measurement in the lumbar spine when degenerative changes are present.⁶⁴ Tenne et al. studied 1044 elderly women (mean age 75 years) longitudinally for 10 years to determine the effect of degenerative lumbar spine changes on DXA measurements, but QCT was not

analyzed.⁶⁵ At baseline, 37% had osteoporosis, and when excluding women with degenerative changes (which may falsely elevate DXA measurements), the rate increased to 47%. Guglielmi et al. also attempted to further define the effect of degenerative changes on lumbar spine BMD measurements and included comparisons to QCT.⁶⁶ They found that trabecular QCT measurements are least impacted by degenerative changes and suggested that, in patients with established lumbar degenerative disease, QCT should be used for volumetric BMD assessment.⁶⁶ Similar to previous studies, they did not report osteoporosis or osteopenia prevalence rates.

Our novel findings have an important place among the existing osteoporosis and spine literature. We believe this is the first series of consecutive lumbar fusion patients with BMD measured by QCT to determine the prevalence of underlying osteoporosis and osteopenia. Contrary to previous studies, we attempted to use QCT-measured BMD in patients with degenerative spinal conditions to screen and identify the underlying disease prevalence. Our osteoporosis prevalence of 14.9% is consistent with previously reported literature on orthopedic and spine patients (range 9.7%–37%). Similarly, osteopenia in our cohort was 43.6%, which is comparable to previous reports (range 21%–57.5%). When excluding patients under 50 years, our rates increased to 17.7% osteoporosis and 48.8% osteopenia. These rates are likely more representative of the majority of patients presenting with degenerative spinal conditions.

This study has many strengths. This comprised a large, consecutive cohort of patients with lumbar degenerative pathology representing a common population presenting to spine surgeons. The BMD measurements were performed by 3 blinded investigators using a reproducible and validated technique. Using QCT instead of DXA or nonstandardized CT Hounsfield unit measurements in patients with lumbar degenerative disease has less variation and is more precise, which increases the reliability of the disease rates. We utilized standardized BMD thresholds defined by the ACR to classify patients in diagnostic cat-

egories, making our results comparable to past and future studies, which can be viewed as an advantage; however, this also is a major limitation. Widespread osteoporosis screening is poorly adopted across all specialties, and similarly QCT and/or utilizing the ACR criteria is not widely available or uniformly used and reported. The gold standard BMD screening remains femoral neck DXA BMD measurement. Within our cohort only, 107 (36%) of the patients underwent preoperative DXA measurement, and we did not analyze the concordance of the QCT versus DXA diagnosis, which may have strengthened the results. However, the QCT ACR criteria were derived by creating thresholds that result in approximately the same fraction of the population being assigned to a diagnostic category as would be based on a femoral neck DXA. We consider using QCT instead of other techniques lends credibility to our reported disease rates with or without DXA. Additionally, our findings do not provide specific fracture risk probability similar to questionnaires like FRAX,³ which incorporates important patient demographic risk factors with or without DXA-derived femoral neck BMD or T-score to calculate 10-year fracture risk probability. We did not complete FRAX questionnaires for our study cohort, and based on current recommendations could not use the QCT-derived BMD in this calculator.^{3,67,68} Future studies should determine if lumbar spine QCT-measured BMD can successfully be used in FRAX. Other weaknesses of this study include limiting the results to patients with lumbar degenerative conditions. These findings are not generalizable to other populations. However, many publications already exist defining osteoporosis risk factors and prevalence in other disease-specific populations; thus, our findings contribute to the study of osteoporosis by defining previously undescribed prevalence rates in a common patient population. Patients only had BMD assessment by QCT, which could be criticized. These patients did not undergo DXA. Adding DXA at the femoral neck (per WHO recommendations) and showing diagnosis concordance would have made our findings more robust. Future studies should aim to reproduce our findings and potentially add DXA measurements to answer this clinical question. Our findings primarily serve to alert clinicians of the high rates of osteoporosis and osteopenia in lumbar fusion patients in hopes that surgeons will institute better screening and early referral and/or treatment. By definition, diagnosing a patient with osteoporosis only quantifies their risk for fragility fractures and not the possible risk of surgical complications. Patients with metabolic bone disease are at higher risk for fixation failure, screw pullout, proximal junctional failure vertebral fracture, and pseudarthrosis. For the purposes of this study, we did not attempt to quantify complications encountered that may or may not be linked to their metabolic bone disease. Defining the link between osteoporosis and surgery complications is an important question that future studies will answer. This study's findings provide important context for future studies and define the importance in previously undiagnosed patients presenting for spinal surgery who may have osteopenia or osteoporosis that should be treated. Another weakness is that we do not have a comparison group. Given the purpose of this study was to define the disease

prevalence, this was beyond the scope of our objectives. Another limitation is if a patient has a previous fracture at L1 or L2, these measurements may not be able to be obtained. We have shown in a previous report there was a high correlation between the L1–2 average and the entire lumbosacral spine.⁶⁹ In patients with factors precluding measurements at L1 or L2, QCT measurements at other levels may be used at the clinician's judgment. The full clinical relevance of diagnosing and treating osteoporosis prior to lumbar fusion procedures is poorly defined and should be investigated in future studies. Emerging recent reports are attempting to answer this question by utilizing osteoporosis pharmacotherapy pre- and postoperatively to prevent surgical complications.^{70–73} These recent studies further emphasize the importance of screening and diagnosing metabolic bone disease in spinal fusion patients.

Conclusions

In a cohort of 296 patients undergoing lumbar fusion surgery, the prevalence of osteoporosis was 14.9% and that of osteopenia was 43.6% as diagnosed by volumetric QCT BMD measurements. Surgeons treating patients with degenerative lumbar spinal pathology should be acutely aware of the high rates of metabolic bone disease and institute screening to identify patients needing medical intervention and fragility fracture prevention. If preoperative lumbar CT scans are obtained, surgeons can utilize these opportunities to perform osteoporosis screening with QCT techniques. Future studies should aim to better define the surgical implications of treating metabolic bone disease prior to lumbar fusion. This is the first report of osteoporosis and osteopenia prevalence rates using QCT instead of DXA in lumbar fusion patients.

References

1. Marcus R, Dempster D, Cauley J, Feldman D (eds). *Osteoporosis*. 4th ed. Elsevier; 2013.
2. Bonjour JP, Theintz G, Law F, et al. Peak bone mass. *Osteoporos Int*. 1994;4(suppl 1):7–13.
3. Watts NB, Ettinger B, LeBoff MS. FRAX facts. *J Bone Miner Res*. 2009;24(6):975–979.
4. Siris ES, Adler R, Bilezikian J, et al. The clinical diagnosis of osteoporosis: a position statement from the National Bone Health Alliance Working Group. *Osteoporos Int*. 2014;25(5):1439–1443.
5. Cameron JR, Sorenson J. Measurements of bone mineral in vivo: an improved method. *Science*. 1963;142(3589):230–232.
6. Cummings SR, Black DM, Nevitt MC, et al. Bone density at various sites for prediction of hip fractures. *Lancet*. 1993; 341(8837):72–75.
7. Hui SL, Slemenda CW, Johnston CC Jr. Baseline measurement of bone mass predicts fracture in white women. *Ann Intern Med*. 1989;111(5):355–361.
8. Johnell O, Kanis JA, Oden A, et al. Predictive value of BMD for hip and other fractures. *J Bone Miner Res*. 2005;20(7):1185–1194.
9. Marshall D, Johnell O, Wedel H. Meta-analysis of how well measures of bone mineral density predict occurrence of osteoporotic fractures. *BMJ*. 1996;312(7041):1254–1259.
10. Melton LJ III, Atkinson EJ, O'Fallon WM, et al. Long-term fracture prediction by bone mineral assessed at different skeletal sites. *J Bone Miner Res*. 1993;8(10):1227–1233.
11. World Health Organization. Assessment of fracture risk and

- its application to screening for postmenopausal osteoporosis: report of a WHO study group [meeting held in Rome from 22 to 25 June 1992]. World Health Organization; 1994. Accessed June 15, 2020. <https://apps.who.int/iris/handle/10665/39142>
12. Liu G, Peacock M, Eilam O, et al. Effect of osteoarthritis in the lumbar spine and hip on bone mineral density and diagnosis of osteoporosis in elderly men and women. *Osteoporos Int*. 1997;7(6):564–569.
13. Orwoll ES, Oviatt SK, Mann T. The impact of osteophytic and vascular calcifications on vertebral mineral density measurements in men. *J Clin Endocrinol Metab*. 1990;70(4):1202–1207.
14. Yu EW, Thomas BJ, Brown JK, Finkelstein JS. Simulated increases in body fat and errors in bone mineral density measurements by DXA and QCT. *J Bone Miner Res*. 2012;27(1):119–124.
15. Kanis JA, Burlet N, Cooper C, et al. European guidance for the diagnosis and management of osteoporosis in postmenopausal women. *Osteoporos Int*. 2008;19(4):399–428.
16. Kanis JA, McCloskey EV, Johansson H, et al. A reference standard for the description of osteoporosis. *Bone*. 2008;42(3):467–475.
17. Kanis JA, Glüer CC. An update on the diagnosis and assessment of osteoporosis with densitometry. Committee of Scientific Advisors, International Osteoporosis Foundation. *Osteoporos Int*. 2000;11(3):192–202.
18. Rüeggsegger P, Niederer P, Anliker M. An extension of classical bone mineral measurements. *Ann Biomed Eng*. 1974;2:194–205.
19. Cann CE, Genant HK. Precise measurement of vertebral mineral content using computed tomography. *J Comput Assist Tomogr*. 1980;4(4):493–500.
20. Cann CE. Quantitative CT for determination of bone mineral density: a review. *Radiology*. 1988;166(2):509–522.
21. Adams JE. Quantitative computed tomography. *Eur J Radiol*. 2009;71(3):415–424.
22. Link TM, Lang TF. Axial QCT: clinical applications and new developments. *J Clin Densitom*. 2014;17(4):438–448.
23. Link TM. Osteoporosis imaging: state of the art and advanced imaging. *Radiology*. 2012;263(1):3–17.
24. Rehman Q, Lang T, Modin G, Lane NE. Quantitative computed tomography of the lumbar spine, not dual x-ray absorptiometry, is an independent predictor of prevalent vertebral fractures in postmenopausal women with osteopenia receiving long-term glucocorticoid and hormone-replacement therapy. *Arthritis Rheum*. 2002;46(5):1292–1297.
25. Khoo BC, Brown K, Cann C, et al. Comparison of QCT-derived and DXA-derived areal bone mineral density and T scores. *Osteoporos Int*. 2009;20(9):1539–1545.
26. Shepherd JA, Schousboe JT, Broy SB, et al. Executive summary of the 2015 ISCD Position Development Conference on advanced measures from DXA and QCT: fracture prediction beyond BMD. *J Clin Densitom*. 2015;18(3):274–286.
27. American College of Radiology. ACR practice guideline for the performance of quantitative computed tomography (QCT) bone densitometry. American College of Radiology; 2008.
28. Steiger P, Block JE, Steiger S, et al. Spinal bone mineral density measured with quantitative CT: effect of region of interest, vertebral level, and technique. *Radiology*. 1990;175(2):537–543.
29. Brown JK, Timm W, Bodeen G, et al. Asynchronously calibrated quantitative bone densitometry. *J Clin Densitom*. 2017;20(2):216–225.
30. Cooper C, Campion G, Melton LJ III. Hip fractures in the elderly: a world-wide projection. *Osteoporos Int*. 1992;2(6):285–289.
31. Kanis JA. WHO Scientific Group Technical Report. Assessment of Osteoporosis at the Primary Health Care Level. University of Sheffield; 2007.
32. Wright NC, Looker AC, Saag KG, et al. The recent prevalence of osteoporosis and low bone mass in the United States based on bone mineral density at the femoral neck or lumbar spine. *J Bone Miner Res*. 2014;29(11):2520–2526.
33. Gullberg B, Johnell O, Kanis JA. World-wide projections for hip fracture. *Osteoporos Int*. 1997;7(5):407–413.
34. Collinge C, LeBus G, Gardner MJ, Gehrig L. Osteoporosis in orthopaedic trauma patients: a diagnosis and treatment protocol. *J Orthop Trauma*. 2008;22(8):541–549.
35. El-Rabbany M, Rosenwasser M, Bhandari M. Managing the burden of osteoporosis: is there a standard of care? *J Orthop Trauma*. 2011;25(suppl 2):S44–S46.
36. Gosch M, Kammerlander C, Roth T, et al. Surgeons save bones: an algorithm for orthopedic surgeons managing secondary fracture prevention. *Arch Orthop Trauma Surg*. 2013;133(8):1101–1108.
37. Sharif KM, Dimitriou R, Giannoudis PV. What is the role of the orthopaedic surgeon in management of fragility fractures? *J Orthop Trauma*. 2011;25(suppl 2):S47–S50.
38. Sorbi R, Aghamirsalam MR. Knowledge of orthopaedic surgeons in managing patients with fragility fracture. *Int Orthop*. 2012;36(6):1275–1279.
39. Tarantino U, Iundusi R, Cerocchi I, et al. Role of the orthopaedic in fragility fracture and in the prevention of a new fracture: SIOT 2009 recommendations. *Aging Clin Exp Res*. 2011;23(2)(suppl):25–27.
40. Rozental TD, Shah J, Chacko AT, Zurakowski D. Prevalence and predictors of osteoporosis risk in orthopaedic patients. *Clin Orthop Relat Res*. 2010;468(7):1765–1772.
41. Glowacki J, Hurwitz S, Thornhill TS, et al. Osteoporosis and vitamin-D deficiency among postmenopausal women with osteoarthritis undergoing total hip arthroplasty. *J Bone Joint Surg Am*. 2003;85(12):2371–2377.
42. Mäkinen TJ, Alm JJ, Laine H, et al. The incidence of osteopenia and osteoporosis in women with hip osteoarthritis scheduled for cementless total joint replacement. *Bone*. 2007;40(4):1041–1047.
43. Lingard EA, Mitchell SY, Francis RM, et al. The prevalence of osteoporosis in patients with severe hip and knee osteoarthritis awaiting joint arthroplasty. *Age Ageing*. 2010;39(2):234–239.
44. Chang CB, Kim TK, Kang YG, et al. Prevalence of osteoporosis in female patients with advanced knee osteoarthritis undergoing total knee arthroplasty. *J Korean Med Sci*. 2014;29(10):1425–1431.
45. Ghosh B, Pal T, Ganguly S, Ghosh A. A study of the prevalence of osteoporosis and hypovitaminosis D in patients with primary knee osteoarthritis. *J Clin Orthop Trauma*. 2014;5(4):199–202.
46. Domingues VR, de Campos GC, Plapler PG, de Rezende MU. Prevalence of osteoporosis in patients awaiting total hip arthroplasty. *Acta Ortop Bras*. 2015;23(1):34–37.
47. Pervaiz K, Cabezas A, Downes K, et al. Osteoporosis and shoulder osteoarthritis: incidence, risk factors, and surgical implications. *J Shoulder Elbow Surg*. 2013;22(3):e1–e8.
48. Chandran S, Alde A, Johnson SR, et al. Prevalence and risk factors of low bone mineral density in psoriatic arthritis: a systematic review. *Semin Arthritis Rheum*. 2016;46(2):174–182.
49. Soda MY, Mizunuma H, Honjo S, et al. Pre- and postmenopausal bone mineral density of the spine and proximal femur in Japanese women assessed by dual-energy x-ray absorptiometry: a cross-sectional study. *J Bone Miner Res*. 1993;8(2):183–189.
50. O'Neill TW, Felsenberg D, Varlow J, et al. The prevalence of vertebral deformity in European men and women: the European Vertebral Osteoporosis Study. *J Bone Miner Res*. 1996;11(7):1010–1018.
51. Padova G, Borzi G, Incorvaia L, et al. Prevalence of osteo-

- porosis and vertebral fractures in acromegalic patients. *Clin Cases Miner Bone Metab*. 2011;8(3):37–43.
52. Viégas M, Costa C, Lopes A, et al. Prevalence of osteoporosis and vertebral fractures in postmenopausal women with type 2 diabetes mellitus and their relationship with duration of the disease and chronic complications. *J Diabetes Complications*. 2011;25(4):216–221.
 53. Armbrecht G, Felsenberg D, Ganswindt M, et al. Vertebral Scheuermann's disease in Europe: prevalence, geographic variation and radiological correlates in men and women aged 50 and over. *Osteoporos Int*. 2015;26(10):2509–2519.
 54. O'Lynn TM, Zuckerman SL, Morone PJ, et al. Trends for spine surgery for the elderly: implications for access to healthcare in North America. *Neurosurgery*. 2015;77(suppl 4):S136–S141.
 55. Cosman F, Kregge JH, Looker AC, et al. Spine fracture prevalence in a nationally representative sample of US women and men aged ≥ 40 years: results from the National Health and Nutrition Examination Survey (NHANES) 2013–2014. *Osteoporos Int*. 2017;28(6):1857–1866.
 56. Olmos JM, Hernández JL, Martínez J, et al. Prevalence of vertebral fracture and densitometric osteoporosis in Spanish adult men: The Camargo Cohort Study. *J Bone Miner Metab*. 2018;36(1):103–110.
 57. Wagner SC, Formby PM, Helgeson MD, Kang DG. Diagnosing the undiagnosed: osteoporosis in patients undergoing lumbar fusion. *Spine (Phila Pa 1976)*. 2016;41(21):E1279–E1283.
 58. Kohan EM, Nemani VM, Hershman S, et al. Lumbar computed tomography scans are not appropriate surrogates for bone mineral density scans in primary adult spinal deformity. *Neurosurg Focus*. 2017;43(6):E4.
 59. Engelke K, Lang T, Khosla S, et al. Clinical use of quantitative computed tomography-based advanced techniques in the management of osteoporosis in adults: the 2015 ISCD Official Positions-Part III. *J Clin Densitom*. 2015;18(3):393–407.
 60. Garner HW, Paturzo MM, Gaudier G, et al. Variation in attenuation in L1 trabecular bone at different tube voltages: caution is warranted when screening for osteoporosis with the use of opportunistic CT. *AJR Am J Roentgenol*. 2017; 208(1):165–170.
 61. Wang DM, Zeng QY, Chen SB, et al. Prevalence and risk factors of osteoporosis in patients with ankylosing spondylitis: a 5-year follow-up study of 504 cases. *Clin Exp Rheumatol*. 2015;33(4):465–470.
 62. Miyakoshi N, Itoi E, Murai H, et al. Inverse relation between osteoporosis and spondylosis in postmenopausal women as evaluated by bone mineral density and semiquantitative scoring of spinal degeneration. *Spine (Phila Pa 1976)*. 2003;28(5): 492–495.
 63. Harada A, Okuizumi H, Miyagi N, Genda E. Correlation between bone mineral density and intervertebral disc degeneration. *Spine (Phila Pa 1976)*. 1998;23(8):857–862.
 64. Yu W, Glüer CC, Fuerst T, et al. Influence of degenerative joint disease on spinal bone mineral measurements in postmenopausal women. *Calcif Tissue Int*. 1995;57(3):169–174.
 65. Tenne M, McGuigan F, Besjakov J, et al. Degenerative changes at the lumbar spine--implications for bone mineral density measurement in elderly women. *Osteoporos Int*. 2013;24(4): 1419–1428.
 66. Guglielmi G, Floriani I, Torri V, et al. Effect of spinal degenerative changes on volumetric bone mineral density of the central skeleton as measured by quantitative computed tomography. *Acta Radiol*. 2005;46(3):269–275.
 67. Leslie WD, Lix LM, Johansson H, et al. A comparative study of using non-hip bone density inputs with FRAX®. *Osteoporos Int*. 2012;23(3):853–860.
 68. Watts NB. The Fracture Risk Assessment Tool (FRAX®): applications in clinical practice. *J Womens Health (Larchmt)*. 2011;20(4):525–531.
 69. Salzmann SN, Shirahata T, Yang J, et al. Regional bone mineral density differences measured by quantitative computed tomography: does the standard clinically used L1-L2 average correlate with the entire lumbosacral spine? *Spine J*. 2019; 19(4):695–702.
 70. Ohtori S, Inoue G, Orita S, et al. Teriparatide accelerates lumbar posterolateral fusion in women with postmenopausal osteoporosis: prospective study. *Spine (Phila Pa 1976)*. 2012; 37(23):E1464–E1468.
 71. Inoue G, Ueno M, Nakazawa T, et al. Teriparatide increases the insertional torque of pedicle screws during fusion surgery in patients with postmenopausal osteoporosis. *J Neurosurg Spine*. 2014;21(3):425–431.
 72. Lubelski D, Choma TJ, Steinmetz MP, et al. Perioperative medical management of spine surgery patients with osteoporosis. *Neurosurgery*. 2015;77(suppl 4):S92–S97.
 73. Kim JW, Park SW, Kim YB, Ko MJ. The effect of postoperative use of teriparatide reducing screw loosening in osteoporotic patients. *J Korean Neurosurg Soc*. 2018;61(sres4): 494–502.

Disclosures

Dr. Carrino reports being a consultant for Pfizer, Covera, Image Analysis Group, Image Biopsy Lab, and SimplifyMedical. Dr. Yang is an employee of Pfizer Inc.

Author Contributions

Conception and design: Carlson, Salzmann, Carrino, Hughes. Acquisition of data: Carlson, Salzmann, Shirahata, Ortiz Miller, Carrino. Analysis and interpretation of data: Carlson, Yang, Sama. Drafting the article: Carlson, Salzmann, Sama, Cammisa, Girardi, Hughes. Critically revising the article: Carlson, Salzmann, Reisener, Cammisa, Girardi, Hughes. Reviewed submitted version of manuscript: Carlson, Salzmann, Carrino, Reisener, Sama, Cammisa, Girardi, Hughes. Approved the final version of the manuscript on behalf of all authors: Carlson. Statistical analysis: Carlson, Yang. Administrative/technical/material support: Carlson, Reisener, Hughes. Study supervision: Hughes.

Supplemental Information

Current Affiliations

J. Yang: Institute For Social and Economic Research and Policy (ISERP), Columbia University, New York, NY.

Correspondence

Brandon B. Carlson: University of Kansas Medical Center, Kansas City, KS. brandonbcarlson@gmail.com.