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ORIGINAL ARTICLE

Effect of including historical height and radius BMD measurement on sarco-osteoporosis prevalence

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Abstract
Background A clinical need exists to improve identification of those who will sustain fragility fractures. Individuals with both osteoporosis (OP) and sarcopenia (SP), so-called "sarco-osteoporosis" (SOP), might be at higher fracture risk than those with OP or SP alone. Approaches to facilitate SOP identification, e.g., use of tallest historical rather than current height and inclusion of radius bone mineral density (BMD) measurement, may be of benefit. This study examined the effect of advancing age on SOP prevalence with and without use of historical tallest height and radius BMD measurement.
Methods Adults age 60+ underwent dual-energy X-ray absorptiometry (DXA) BMD and total body composition measurement. OP and SP were defined using standard criteria: T-score ≤−2.5 at the lumbar spine or hip and appendicular lean mass (ALM)/current height^2 <5.45 kg/m^2 (female) and <7.26 kg/m^2 (male). Proposed "sensitive" SP criteria used historical tallest height instead of current height, while "sensitive" OP criteria added the 1/3rd radius T-score. The primary outcome was SOP prevalence by decade (60–69, 70–79, 80+).
Results A total of 304 individuals (146 M/158 F) participated. OP, SP and SOP prevalence were higher in older adults and increased ($p<0.05$) with the "sensitive" criteria. SOP prevalence was lower than that of OP or SP and increased (standard/sensitive) criteria from 1.1 % / 4.5 % in the 60–69 years age group to 10.4 % / 21.9 % in the 80+ years age group.
Conclusions SOP prevalence is higher in older adults. Use of historical tallest height and 1/3rd radius BMD increases SOP prevalence. Future studies need to assess whether having SOP increases fracture risk and whether use of tallest height and/or one-third radius BMD improves fracture risk prediction.

Keywords Sarcopenia · Osteoporosis · Age · Radius BMD · Sarco-osteoporosis

1 Introduction

A clinical need exists to optimally identify those who will sustain fragility fractures. Simply utilizing bone mineral density (BMD) measurement alone is not adequate, as the majority of people who sustain osteoporosis-related fractures do not have osteoporosis by BMD T-score [1–4]. As such, major efforts to improve fracture risk estimation continue, e.g., development of calculators such as FRAX®, Garvan and Qfracture that include clinical risk factors [5–11]. However, using existing calculators some people at low estimated risk sustain fractures and not all at high risk do fracture. Clearly, improved fracture risk assessment is needed.

Fracture risk increases dramatically with advancing age [12, 13]. This increase is much greater than the corresponding BMD decline [14, 15]. As such, "age" encompasses factors that increase fracture risk, including, among others, declining functional status and increased falls risk. Sarcopenia, the age-related decline in muscle mass and function, is associated with increased risk for falls, frailty and fractures [16–24] and may well explain some/much of the increased risk currently attributed to "age." Consistent with this, in the Dubbo study age was not associated with fracture risk after correction for muscle strength and body sway [25, 26]. It is possible that individuals with both osteoporosis and sarcopenia ("sarco-osteoporosis") are at

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greatest fracture risk [27–30]. Indeed, a recent report of over 300 women with hip fracture found 45 % to have both osteoporosis and sarcopenia [31]. Therefore, evaluation of sarco-osteoporosis as a fracture risk factor, and assessment of approaches to improve this diagnosis, is appropriate.

Current consensus sarcopenia definitions include appendicular lean mass (ALM) adjusted for height (ALM/ht^2) [20, 22, 32]. However, height loss is common with advancing age and confounds body mass index (BMI) and body composition assessment in older adults [33, 34]. As many older adults are shorter than their tallest height, their ALM/ht^2 value is higher than if no height loss had occurred thereby making them less likely to be classified as sarcopenic. Moreover, differing amounts of height loss between individuals will introduce unappreciated variability into any clinical cut point ALM/ht^2 ratio selected to include in the definition of sarcopenia. Recognizing this potential confounder, some prior sarcopenia studies have adjusted for height loss [34, 35]. However, to our knowledge, the effect of using tallest reported rather than current height on sarcopenia prevalence has not been reported.

BMD measurement is important in fracture risk estimation. However, spine BMD as measured by dual-energy X-ray absorptiometry (DXA) is commonly elevated in older adults by degenerative changes [36–38]. Proximal femur measurements, while less frequently affected, are not immune to the impact of degenerative changes [39]. In contrast, BMD measurement at the one-third radius is unaffected by degenerative changes. Prior work finds radius BMD measurement to be important in older adults [40], and documents the ability of this site to predict fracture risk [41]. Thus, it is possible that routine performance of one-third radius BMD measurement in older adults might improve fracture risk prediction.

The overarching purpose of this work is to suggest potential approaches that are easily applicable that may enhance fracture prediction and to begin their evaluation. To this end, we hypothesized that use of historical tallest height in the ALM/ht^2 ratio and inclusion of radius BMD T-score might enhance identification of sarcopenia and osteoporosis, respectively, thereby facilitating sarco-osteoporosis recognition and potentially fracture risk estimation in older adults. To test this hypothesis, the aims of this study in a group of adults age 60+ years were to: (1) evaluate the effect of inclusion of one-third radius BMD measurement on T-score distribution and use of historical height vs. current height on the ALM/ht^2 ratio and (2) define the prevalence of sarcopenia, osteoporosis and sarco-osteoporosis with and without using one-third radius BMD and historical height. Here we report the effect of these approaches on prevalence of osteoporosis, sarcopenia and sarco-osteoporosis in a convenience sample of 304 community dwelling adults age 60 years and over.

2 Methods

2.1 Participants

Data from three studies performed at the University of Wisconsin Osteoporosis Clinical Research Program were included in this analysis. These studies include the MIDUS (Mid-life in the United States) II study, "Precision," a DXA precision research study comparing BMD and body composition between two GE Healthcare Lunar densitometers, (iDXA and Prodigy) and "Jump," a study examining jump mechanography as a tool to assess function in older adults. Participants from the MIDUS Biomarker Project study (n=44), "Precision" (n=164) and "Jump" (n=96) comprise a sample of older community dwelling adults, primarily from the Madison, WI area. All studies were reviewed and approved by the University of Wisconsin Health Sciences IRB and all participants signed an informed consent document prior to conduct of any study procedure.

2.2 Bone mineral density and body composition measurement

A GE Healthcare Lunar (Madison, WI) Prodigy or iDXA densitometer was used for all BMD and body composition measurements. Excellent BMD and body composition assessment agreement is observed between the two densitometers used for this study [42]. Routine densitometry quality assurance procedures were followed; no instrument drift or shift was detected during these studies. Scans of the lumbar spine, proximal femur, non-dominant radius and total body were performed in routine clinical manner by International Society for Clinical Densitometry (ISCD) certified technologists. The lowest BMD T-score of the lumbar spine, femoral neck, total proximal femur or one-third radius was chosen to define osteoporosis using the World Health Organization (WHO) T-score based classification system. The lowest T-score at any of the above sites was used to classify each individual's skeletal status as recommended by the ISCD [43]. ALM was used to calculate the ALM/height^2 ratio. ALM includes only lean mass, excluding fat and bone mass, of the arms and legs as depicted in Fig. 1. Height for this ratio was based either on stadiometer-measured height performed on the day of DXA scanning or by participant self-reported tallest historical height. Commonly utilized definitions of osteoporosis and sarcopenia were applied, i.e., a T-score ≤ -2.5 at the lumbar spine or hip [44] and ALM/current height^2 <5.45 kg/m^2 (female) and <7.26 kg/m^2 (male) [32]. For the "sensitive" definitions, a one-third radius T-score (derived using the GE normative gender matched database) of ≤ -2.5 was considered osteoporosis and the ALM/ht^2 ratio utilized historical tallest height

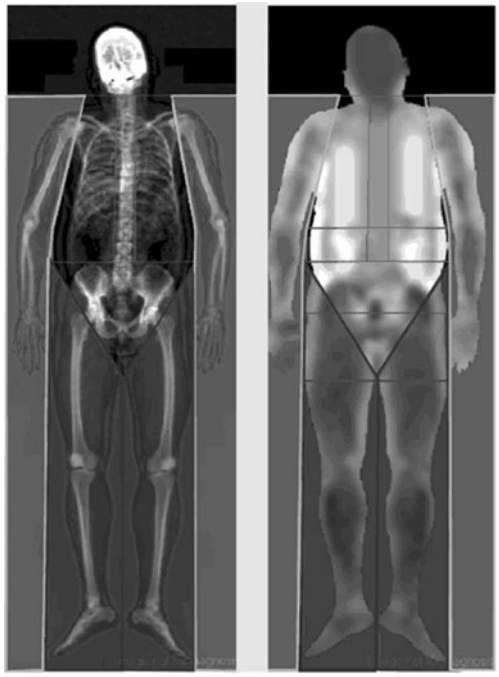


Fig. 1 Appendicular lean mass regions of interest. Examples of the bone (*left*) and soft tissue (*right*) DXA image of an individual. Appendicular lean mass (*ALM*) is defined as the lean mass, excluding bone and fat, in the arms (*light gray region*) and legs (*dark gray region*)

and the sarcopenia cut points noted above of 5.45 and 7.26 kg/m^2 were applied.

The potential importance of using a DXA site not affected by degenerative change was explored by defining the prevalence of obvious degenerative disease. To this end, all DXA spine images were reviewed by one experienced densitometrist (NB). Degenerative changes were considered to be present if obvious osteophytes, vertebral fractures, or focal degenerative changes involving less than an entire vertebral body, or a ≥1 T-score discrepancy between vertebral bodies was observed [43].

2.3 Statistical analysis

Demographic comparisons and evaluation of T-score comparability were performed using *t*-tests with Statview (Cary, NC) software. Pearson and Fisher chi-square statistics (Analyze-It; Leeds UK) were used to compare the prevalence of osteoporosis, sarcopenia and sarco-osteoporosis using "standard" or "sensitive" definitions in the three age groups (60–69, 70–79 and 80+ years).

3 Results

3.1 Study participants

A total of 304 individuals (158 females, 146 males) age 60 and above were included in this cross-sectional analysis. Their age and BMI (mean, SD and range) was 75.5 (7.5) years (60–95) and 27.1 (4.9) kg/m^2 (15.1–51.6), respectively. The male cohort was slightly ($p<0.05$) older. As could be expected, the males were taller and heavier ($p<0.001$) than the females; however, mean BMI did not differ. BMD T-score was lower ($p<0.05$) at all sites in women. Similarly, ALM/ht^2 was lower ($p<0.001$) in women. Demographic data is summarized in Table 1. Participants were stratified by decade of age: 60–69 ($n=89$); 70–79 ($n=119$); and 80+ ($n=96$).

3.2 Prevalence of degenerative changes/effect of including one-third radius measurement on T-score distribution

Obvious degenerative changes (examples in Fig. 2) were apparent on the DXA image in virtually all (93 %) of these volunteers. Only 14 of 158 (9 %) of the women and eight of 146 (5 %) of these men had no apparent degenerative changes. As a result, lumbar spine T-scores deviated from normal to a lesser degree than in the radius in both men and women ($p<0.0001$; Fig. 3). Of those 14 individuals without obvious degenerative changes on their DXA image, 59 % were less than age 70.

3.3 Height loss/effect on ALM/height^2

Self-reported tallest height was greater than current stadiometer-measured height in 97 % (296/304) of study participants. Males had a larger mean reported height loss than females (4.5 vs. 3.7 cm; $p<0.05$; Table 1; Fig. 4a). Use of reported tallest height in the ALM/ht^2 ratio reduced this

Table 1 Study participant demographic data

	Age (years)	BMI (kg/m^2)	Height loss (cm)	L1–L4 T-score	Femoral neck T-score	Total femur T-score	One-third radius T-score	ALM/height^2 (kg/m^2)
Female $n=158$	74.5* (7.0)	27.1 (5.5)	3.7* (2.9)	−0.7† (1.7)	−1.5* (0.9)	−1.0* (1.1)	−1.9† (1.4)	6.5† (1.0)
Male $n=146$	76.5 (7.9)	27.2 (4.0)	4.5 (3.1)	+0.9 (2.1)	−1.1 (1.0)	−0.7 (1.1)	−0.5 (1.1)	8.1 (1.0)

Data are presented as mean (SD)

Different than males: *$p<0.05$; $^\dagger p<0.001$

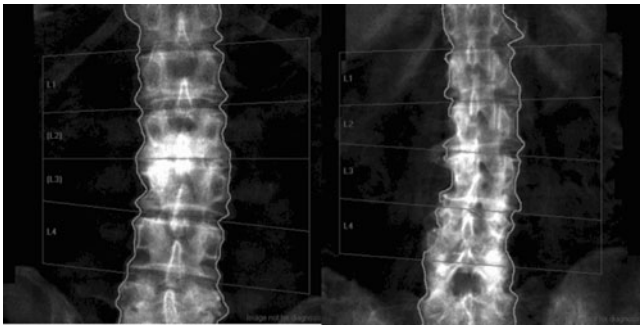


Fig. 2 Examples of spinal degenerative changes. Examples of what were considered as "obvious" degenerative changes on the DXA images are presented here. The image on the *left* is a 70-year-old man in whom focal abnormalities at L2 and L3 are apparent. The individual vertebral body T-scores are consistent; from L1 to L4 these values are +1.1, +4.5, +4.2 and +1.7; thus, a >1 T-score difference is present between adjacent vertebrae. The 86-year-old female on the *right* has apparent degenerative changes at L2, L3 and L4 with obvious osteophytes at L2 and L3. T-score differences between adjacent vertebrae were observed with values from L1 through L4 being +0.2, +1.7, +3.5 and +4.1, respectively

value by a mean of 4.9 % in men and 4.4 % in women (Fig. 4b).

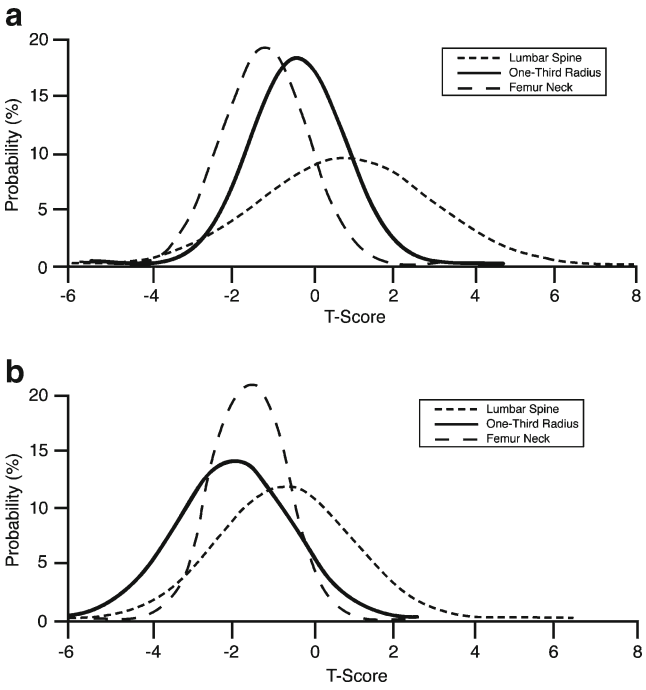


Fig. 3 Comparison of lumbar spine, femur neck and one-third radius T-scores in men and women. Depicted are distribution curves (using a normal continuous fit function) of lumbar spine, femur neck and one-third radius T-scores in men (**a**) and women (**b**). In both genders mean BMD T-scores were the higher at lumbar spine compared to the femur neck or the one-third radius site (all $p<0.0001$). Mean BMD T-scores at the femur neck were higher than the one-third radius in females but lower in males (all $p<0.01$; see Table 1 for T-score values and their standard deviations). The broad range of lumbar spine T-scores in males is striking with values above +5 in some men. This was not the case in the one-third radius site

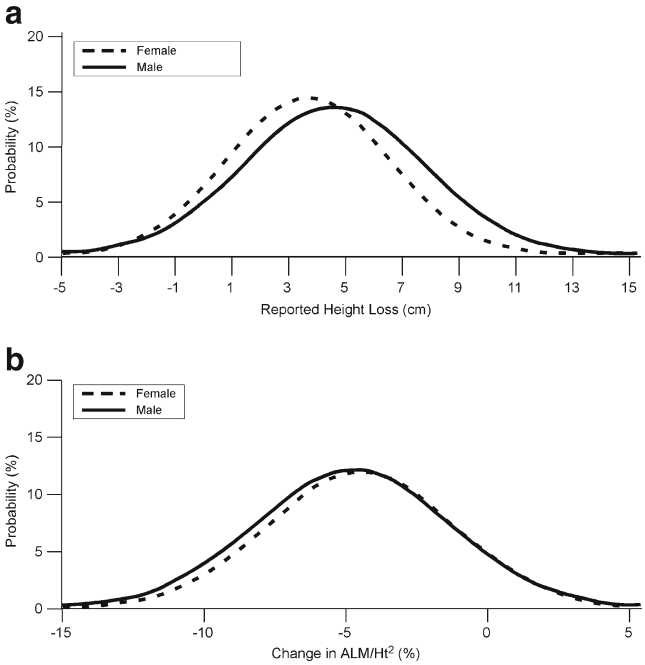


Fig. 4 Historical height change and effect on ALM/Ht^2 ratio. The distribution curves (using a normal continuous fit function) for the amount of reported historical height loss (**a**) shows a mean of 4.5 cm in men and 3.7 cm in women. The variability of height loss is striking with some individuals reporting more than 10 cm of height loss. The negative values (suggesting height gain) are evidence of limitations of historical tallest height. The distribution curves of percentage change of using reported historical height loss instead of current height show that in both genders the mean ALM/height^2 ratio was decreased (4.4 % in females and 4.9 % in males)

3.4 Prevalence of sarcopenia, osteoporosis and sarco-osteoporosis

The prevalence of sarcopenia increased with age ($p<0.01$) using either the standard or "sensitive" criteria (Fig. 5a). The "sensitive" criteria identified more individuals with sarcopenia than the standard criteria ($p<0.0001$). Overall, 15 % of this cohort was classified as sarcopenic with standard criteria whereas the sensitive criteria identified 26 %.

Osteoporosis prevalence increased with age ($p<0.001$) with both the standard and "sensitive" criteria (Fig. 5b). The "sensitive" criteria identified more individuals with osteoporosis than the standard criteria ($p<0.0001$). Overall, 17 % of this cohort was classified as osteoporotic with standard criteria whereas the sensitive criteria identified 29 %.

Sarco-osteoporosis prevalence increased with age ($p<0.05$) using either the standard or "sensitive" criteria (Fig. 5c). The "sensitive" criteria identified more individuals with sarco-osteoporosis than the standard criteria ($p<0.0001$). The prevalence of osteoporosis and sarcopenia were similar; however, the prevalence of sarco-osteoporosis was less than either ($p<0.0001$). Specifically, 5 % of the entire cohort was

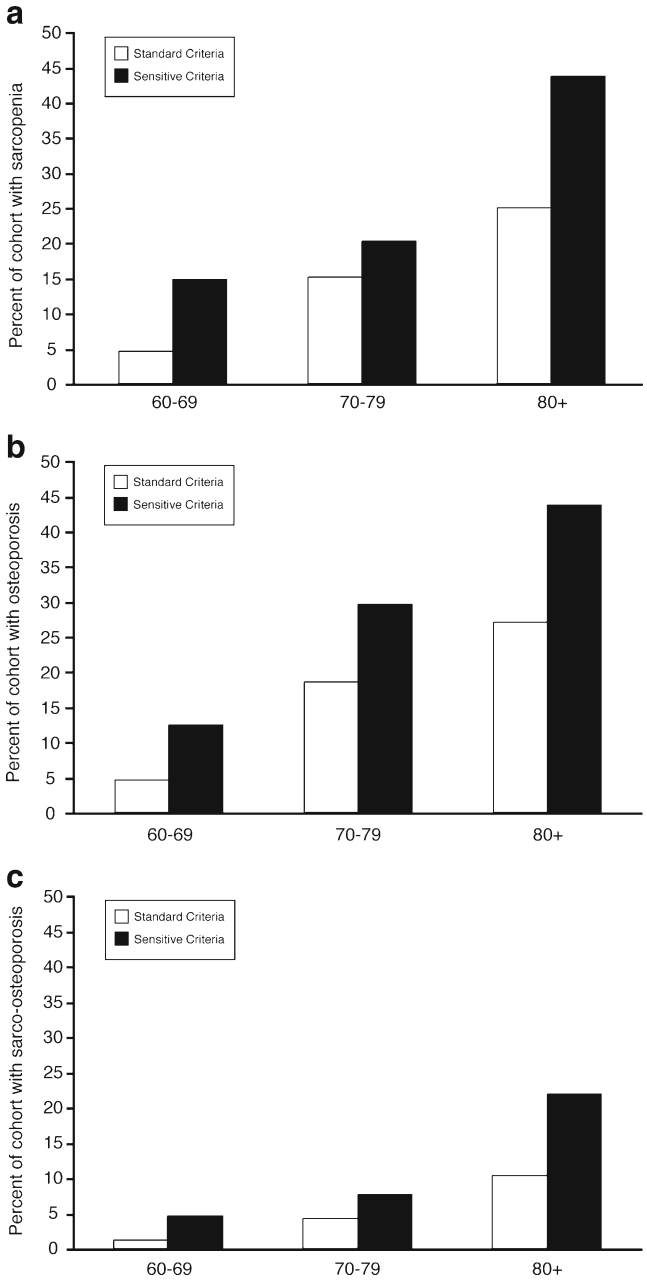


Fig. 5 Prevalence of sarcopenia, osteoporosis and sarco-osteoporosis by decade using standard or sensitive criteria. Sarcopenia was more common in individuals age 80+ than 70–79 and 60–69 years ($p<0.01$) regardless of criteria used (**a**). Significantly more ($p<0.0001$) individuals had sarcopenia using the sensitive criteria (ALM/reported historical tallest height^2) compared to standard criteria (ALM/current height^2). Similarly, osteoporosis was more common in individuals age 80+ than 70–79 and 60–69 ($p<0.001$) regardless of criteria used (**b**). Significantly more ($p<0.0001$) individuals had osteoporosis using the sensitive criteria (lowest T-score from hip, lumbar spine and one-third radius) compared to standard criteria (lowest T-score of hip and lumbar spine only). Sarco-osteoporosis was more common in individuals age 80+ than 70–79 and 60–69 ($p<0.05$) regardless of criteria used (**c**). Significantly more ($p<0.0001$) individuals had sarco-osteoporosis using the sensitive criteria compared to standard criteria

classified as having sarco-osteoporosis with standard criteria whereas the sensitive criteria identified 11 %.

4 Discussion

In this cross-sectional study of community-dwelling adults age 60 and older, the prevalence of osteoporosis, sarcopenia and sarco-osteoporosis was higher in older individuals. The prevalence of osteoporosis and sarcopenia was similar, whereas sarco-osteoporosis was less common. Use of potentially more sensitive criteria (i.e., using tallest historical height instead of current height to define sarcopenia and including 1/3 radius BMD T-score in the definition of osteoporosis) increased the prevalence of sarcopenia, osteoporosis and sarco-osteoporosis. This is not surprising as both degenerative changes, which elevate DXA-measured BMD, and reported height loss were present in virtually all of these individuals.

To our knowledge, only very limited data currently exist on the prevalence of sarco-osteoporosis. Clearly, the prevalence of sarcopenia, osteoporosis and sarco-osteoporosis will vary depending on the population studied (i.e., prevalent hip fracture, included gender, age group and degree of frailty). As noted in the introduction, the prevalence of sarco-osteoporosis has been reported as high as 45 % in individuals who already suffered a hip fracture [31]. Other authors report percentages closer to those found in this study [19, 30]. Similar to the results reported here, most studies that divided participants by age observed a higher prevalence in older age groups [19, 29–31].

Age is accepted as a major contributor to fracture risk [6, 12]. It is probable that there are many risk factors "hidden within age" contributing to this increased risk; evidence is increasing that sarcopenia is one such factor [19, 25–28, 31, 45–47]. Importantly, sarcopenia is closely linked to falls and increased risk of falling is a well-established contributor to fracture [10, 26, 48, 49]. In addition to increasing falls risk, sarcopenia might also decrease bone strength by reducing mechanical loading to the skeleton. Reduction of mechanical stimulation could result from decreased maximal force that weaker muscles produce and/or less time that the skeleton is loaded due to relative immobility [50–53]. As such, the concept of "sarco-osteoporosis," seems likely to facilitate fracture risk estimation [27, 28, 31]. Moreover, simple approaches such as described here (radius BMD and use of historical height) with potential to enhance diagnostic sensitivity for sarco-osteoporosis, may have direct clinical applicability in improving fracture risk estimation.

Consideration of clinical risk factors for fracture in addition to BMD has significantly changed osteoporosis treatment decision-making. However, none of the currently available fracture risk models perfectly predict fragility

fractures. Potential limitation of FRAX® (www.shef.ac.uk/frax), relevant to this study is that only femoral neck (not spine or radius) BMD is considered. Furthermore, sarcopenia, muscle function and falls are not able to be included in this algorithm given limitations of the observational cohorts used to derive FRAX® [54–56]. A second method to estimate fracture risk developed by the Garvan institute (www.garvan.org.au/bone-fracture-risk) does include history and number of falls within the past year but no measure of muscle mass or function [10, 11].

It could be argued that measurement of BMD at additional skeletal sites, i.e., the forearm, is not necessary when BMD is measured at both the spine and femoral neck. However, lumbar spine BMD is elevated by degenerative changes that are present in virtually all older adults, 93 % in this study. Such a high prevalence is not unique to this cohort. For example, a study of 300 Australian men and women age 60 and above found X-ray evidence of osteophytes in 69 % of all males and females, disc narrowing in 67 % and apophyseal osteoarthritis (posterior element disease) in 99 % of participants [57]. Another study of 600 Japanese women age 60 and above found osteoarthritic changes in 96 % of individuals on lumbar spine X-rays [58]. As could be expected, spinal degenerative changes increase lumbar spine BMD measured by DXA; on average by 15–24 % [57–59]. Additionally, femoral neck BMD measurement may also be elevated by degenerative changes [39]. Other femoral neck BMD measurement confounders include internal artifacts, fat panniculi and anatomic variations [60, 61]. It seems likely that such confounders are one contributor to the less than ideal predictive capability of tools such as FRAX®. As such, evaluations of potential approaches to enhance fracture prediction capability, potentially including forearm BMD measurement, are appropriate.

Limitations of this study include relatively small sample size and cross-sectional nature. Furthermore, in this study sarcopenia could only be defined based on DXA measured ALM/ht^2 ratio, as muscle function data were not available in all cohorts used for this analysis. Current consensus definitions for sarcopenia appropriately use both muscle mass and muscle function parameters as the combination of these measures improve the prediction of poor outcomes [20, 22]. Additionally, use of self-reported tallest height is inferior to serial height measurements over time as there is risk for recall errors and bias. Two systematic reviews have identified a tendency in adults to overestimate historical tallest height, leading to a greater height loss than if prospectively measured. [62, 63] Despite this, self-reported height loss has apparent clinical applicability and, importantly, predicts clinical outcomes including vertebral fractures, mortality and morbidity [62, 64, 65]. Future study to further define the accuracy of height recall, and moreover to identify optimal approaches to determining tallest height, is needed. An additional limitation is that data regarding prior fragility fracture or other outcomes for sarco-osteoporosis are not available in this study. Future work is needed in longitudinal studies to evaluate the effect of sarco-osteoporosis diagnosis on risk for fragility fracture and also to explore the utility of using historical tallest height and radius BMD measurement on this diagnosis.

5 Conclusion

In conclusion, sarco-osteoporosis is present in ~10 % of adults over age 80 and the prevalence is higher in older people. Using simple, but potentially more sensitive criteria, i.e., adding the one-third radius BMD T-score and using tallest historical height, rather than current height, in the sarcopenia ALM/height^2 calculation identifies more individuals as potentially being at risk. Assessment of both bone and muscle mass/function in older adults could potentially enhance fracture risk prediction; research utilizing existing longitudinal studies in which bone and muscle status was carefully defined and fractures rigorously captured is needed to evaluate the potential utility of sarcopenia and sarco-osteoporosis consideration in fragility fracture risk assessment. Although no causal attribution is possible in this analysis, sarco-osteoporosis may explain some of the increase in fracture risk currently related to “age.”

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Conflict of interest Bjoern Buehring, Diane Krueger, and Neil Binkley do not have any potential conflicts of interest.

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