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Bone density measured on sagittal reconstructed CT is highly correlated with axial CT but both measurements are only moderately correlated with DEXA T-scores

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ABSTRACT

Background: During the preoperative evaluation of a patient being considered for spinal surgery, Dual-energy x-ray absorptiometry (DEXA) has been traditionally used to diagnose poor bone mineral density (BMD) as a risk factor. As ordering a DEXA can add cost and delay diagnosis, spine surgeons have more recently began to use Hounsfield Units (HU) measured on computed tomography scans (CT) as a measure of BMD. The aim of our study was to evaluate associations between DEXA and HU on lumbar spine CT scans.
Methods: Forty-two patients (32 female, 10 male, mean age = 67.7 years) with DEXA and lumbar spine CT scans performed within one year of each other were identified. DEXA T-scores were collected from the hip, forearm and L1-L4. HU was determined using the maximum region of interest within the cancellous area in the mid-vertebral body from L1-L4 in the sagittal and axial planes.
Results: Using the lowest T-score, 8 (19 %) cases were osteoporotic and 25 (60 %) were osteopenic. Statistically significant differences in HU were seen in osteoporotic cases (Axial HU = 59.2, Sagittal HU = 61.1, $p = 0.006$) compared to osteopenic (Axial HU = 119.8, Sagittal HU = 122.9) and normal cases (Axial HU = 141.2, Sagittal HU = 142.3). There were moderate associations between the spine T-scores and CT HUs (Axial HU:$r^2 = 0.50$, Sagittal HU:$r^2 = 0.49$, $p < 0.001$), weak associations between the Axial HU ($r^2 = 0.48$, $p < 0.000$) and Sagittal HU ($r^2 = 0.48$, $p < 0.000$) with hip T-scores, and no correlations with forearm T-scores. There were strong associations between Axial HU and Sagittal HU ($r^2 = 0.98$, $p < 0.001$).
Clinical relevance: The results of the current study show a strong association between the sagittal and axial vertebral HU measurements, which supports the clinical use of either measurement technique. The weak correlation between T-scores and HU is consistent with prior studies and warrants future studies to determine which modality will better predict postoperative mechanical failures in patients undergoing spinal surgery.
Level of Evidence: III.

1. Introduction

Osteoporosis is a common health problem among the increasingly aging population [1,2] and yet it has low detection and treatment rates [3–5]. Evaluating bone quality in elderly patients who are scheduled for instrumented spine surgery is important [6] as without pre-operative optimization, there is a significantly increased rate of failure [7–10]. The progressive decline in bone health from bone fragility through bone mass reduction and microarchitecture structural deterioration are commonly cited reasons for orthopedic construct failure [10,7,8]. Currently, Bone Mineral Density (BMD) is considered the best surrogate to evaluate vertebral strength, but it also correlates well with fracture risk and surgical outcomes [6–12].

For decades, dual-energy X-ray absorptiometry (DEXA) scans have

Abbreviations: DEXA, Dual-energy x-ray absorptiometry; BMD, bone mineral density; HU, Hounsfield Units; CT, computed tomography; ROI, region of interest (ROI); SagHU, Hounsfield Units on Sagittal images; AxHU, Hounsfield Units on Axial images; 2D, two Dimensional; ANOVA, one-way analysis of variance.

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been considered the gold standard for measuring BMD with low cost, ease of use, and minimum exposure to radiation [4]. It provides regional BMD estimates from two Dimensional (2D) images of the forearm, hip, and spine [1,2,13,4]. Despite the clinical importance currently attributed to this modality, it has some limitations. Vertebral compression fractures and osteoarthrosis with sclerosis are known to interfere with the accuracy of this test [14,15]. In such cases, DEXA scan tends to overestimate the BMD, which could account for the underdiagnosis of osteoporosis [3–5,14,15].

In 2011, Schreiber et al. introduced a simple method for BMD assessment using Hounsfield unit measurements on conventional CT scans [16]. This method is attractive to spine surgeons as they routinely order lumbar CT scan in planning for instrumented spine surgery [9,14,17–20]. Despite the advantages of CT scan, studies have shown only a moderate correlation between HU and DEXA measurements [9,16,19]. The objective of this study is to evaluate the accuracy with which bone quality is judged by CT scan utilizing Hounsfield unit measurements for Regions of Interest (ROI) on both the axial and sagittal reconstructed CT images when compared to DEXA scan T-scores.

2. Methods

Following Institutional Review Board approval, a single institution, retrospective study was performed using a database querying for patients that had undergone both a DEXA scan and lumbar spine CT scan as part of their standard pre-operative workup from June 2013 to June 2021. DEXA and CT are commonly performed during the pre-operative planning process for instrumented fusion surgeries when a concern regarding bone quality exists. Patients who had these modalities completed more than a year apart were excluded in order to mitigate the possible effect of progressive bone density degradation. Patients who had spine instrumentation were also excluded as this falsely inflated ROI measurements on CT scan. Demographic information collected for each patient included age at time of imaging, gender, weight, height, smoking history, relevant comorbidities, and ASA grade.

CT lumbar spine ROI measurements were made at L1, L2, L3, and L4 in both the sagittal and axial planes. The most commonly cited method found in literature where the maximum ROI within the cancellous region of the mid-vertebral body was measured was used. ROI units were then categorically qualified as normal, osteopenic, or osteoporotic based off the current values reported in the literature, [17] with normal bone having HU > 135 with ranges below that qualifying as osteopenia or osteoporosis. For DEXA measurements, all available T-scores were collected from the hip, forearm, and lumbar vertebrae (L1-L4).

2.1. Statistical analysis

All statistical analyses were performed using IBM SPSS v28.0 (Armonk New York). Descriptive data, lowest HUs in the sagittal and axial planes, T-scores are presented as means and standard deviations. Lowest average HUs were compared to T-score classification of bone mineral density using one-way analysis of variance (ANOVA). Post-hoc Tukey's test was performed to assess for homogeneity. Correlation coefficients using the Spearman's Rho and regression analysis was performed to determine associations between Sagittal HUs, Axial HUs, HUs, Spine, Hip and Forearm T-scores. Statistical significance was defined as $p < 0.05$.

3. Results

The mean age of the 42 cases included in the analysis was 67.74 ± 11.64 years and 32 (76.2 %) were female. Mean Body Mass Index was 30.53 ± 7.51 kg/m^2, and 5 (11.9 %) patients were tobacco users. The majority of females (24, 75 %) were post-menopausal. Three females and one male was on alendronate and one female was on denosumab. DEXA and lumbar CT scans were performed a mean of 124.30 ± 112.08 days apart, with no cases exceeding a one year interval (Table 1). Twenty-seven (64 %) of the patients had a lumbar fusion surgery while 15 were not scheduled for surgery.

Based on the lowest T-score, 8 (19 %) cases were classified as osteoporotic and 25 (60 %) as osteopenic. A statistically significant difference in HU was observed when comparing osteoporotic cases (Axial HU = 59.2, Sagittal HU = 61.1, $p = 0.006$) to osteopenic (Axial HU = 119.8, Sagittal HU = 122.9) and normal cases (Axial HU = 141.2, Sagittal HU = 142.3) (Fig. 1). When subjects are categorized as osteoporotic, osteopenic or normal based on CT and DEXA, all the patients who were osteoporotic on DEXA were osteoporotic on CT. However, 20 patients who were osteoporotic on CT (Lowest HU less than 135) were normal or osteopenic on DEXA (Table 2). If DEXA is considered the gold standard, then CT based BMD has a sensitivity of 54 %, specificity of 58 %, positive predictive value of 72 % and negative predictive value of 39 % to detect osteopenia or osteoporosis.

Spearman's rho test demonstrated moderate associations between spine T-scores and CT HUs (Axial HU:$r^2 = 0.50$ Sagittal HU:$r^2 = 0.49$, $p < 0.001$). Additionally, weak associations were observed between Axial HU ($r^2 = 0.48$, $p < 0.000$) and Sagittal HU ($r^2 = 0.48$, $p < 0.000$) with hip T-scores, and no correlations were observed with forearm T-scores (Table 3).

Analysis of the consistency between Axial HU and Sagittal HU measurements exhibited a strong association ($r^2 = 0.98$, $p < 0.001$). The number of cases where the lowest HU measurement was obtained at the same level in both axial and sagittal planes was 24 (57 %). Additionally, the lowest HU was most often recorded at L3 in both axial (41 %) and sagittal (33 %) planes.

4. Discussion

The findings of the current study show consistency with the existing literature with regard to the weak to moderate correlation between DEXA scan and CT HU measurements and their classification of BMD [9,16,19,21]. A noteworthy finding in this study was the high correlation between axial and sagittal CT HU measurements (correlation coefficient = 0.979). Since Schreiber et al's introduction of their method for measurement, most studies have utilized L1-L4 axial and/or sagittal cuts for the optimal evaluation of BMD [14,16–19]. A novel finding in this study is utilization of either plane with the assumption that you will have a similar finding in the complementary plane at the same level.

4.1. DEXA versus other imaging modalities

While only a small number of studies have compared CT HU measurements with DEXA scans, [14–17] there have been a number of other studies for other modalities. MRI as a modality for assessing bone mineral density was considered in several studies for general osteoporosis assessment as well as specifically for spine patients [22–24] due to the routine use of MRI in the assessment of lumbar pathology [25]. Recent studies showed that CT HU measurement had stronger correlation than MRI with DEXA scans, but overall both had only a moderate correlation with DEXA scans [9,17]. Mild to moderate correlation of CT measurements and DEXA scans indicate that while one may be indicative of poor

Table 1
Summary of Demographic Information.

N	42
Age, years, Mean (SD)	67.74 (11.64)
Females, N (%)	32 (76 %)
BMI, kg/m^2, Mean (SD)	30.53 ± 7.51
Tobacco user,, N (%)	5 (12 %)
Days between DEXA and CT, Mean (SD)	124.30 (112.08)
Lowest Sagittal HU, Mean (SD)	121.26 (51.36)
Lowest Axial HU, Mean (SD)	119.87 (49.75)
Lowest T-score, all sites, Mean (SD)	−1.50 (1.24)

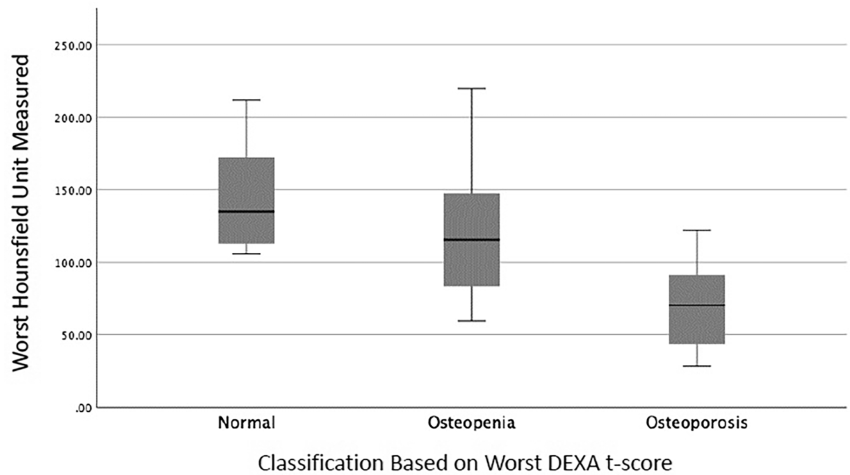

Fig. 1. Boxplots of lowest HU to lowest DEXA T-score classification.

Table 2
Cross tabulation of CT Scan and DEXA T-scores.

DEXA T-score	CT Scan	
	HU < 135	HU ≥ 135
>-1.0	7	5
1.0 to −2.5	11	14
<2.5	0	9

BMD, the other may categorize a patient as having normal density resulting in a mismatch that can affect long term outcomes. A recent *meta*-analysis classified osteoporosis as HU measurements of < 135, but did not clarify these findings in conjunction with existing BMD evaluations using other advanced imaging [17]. The current study shows that CT may overestimate the presence of osteoporosis if DEXA is considered the gold standard. However, the reverse may be true. That is HU may be more accurate than DEXA in detecting the presence of osteoporosis.

A recent systematic review by Ahmad et al analyzed the previously published literature and reported only a moderate correlation between DEXA and CT HU with pooled r^2 values ranging from 0.41 to 0.6 [26].

4.2. Limitations of DEXA

For decades, DEXA scans have served as the gold standard for determination of bone quality [2] with only a relatively recent shift towards utilization of ROI and HU measurements [1,13]. A recent study showed that while a complete DEXA scan should include measurements from the forearm, hip, and lumbar spine, not all centers have protocols that utilize all three body locations [4]. The same study found that the addition of a third location, the forearm, leads to a 17 % increase in the diagnosis of osteoporosis/osteopenia [4]. Recent studies have recently pointed out that different cut-off T-Score values apply to risk calculation in Caucasian and East- Asian populations, indicating that the current imaging knowledge base for osteoporosis is lacking sufficient standardization to enable effective prognostication [26].

4.3. Limitations of the current study

The findings of this study should be considered within the context of certain limitations. First, this was a retrospective study conducted within a single institution and is representative of its own unique biases. The patients were being assessed for a variety of instrumented lumbar fusion procedures. Future studies on this topic would benefit greatly from a prospective nature. Second, the CT and DEXA scans used for interpretation were not all performed at a single institution. Many of

Table 3
Spearman Rho Correlation Coefficients.

	CT Scan Region of Interest (ROI) Hounsfield Units (HU											Worst T-score		
	Sagittal					Axial					Worst CT Scan HU			
CT Scan ROI HU	L1	L2	L3	L4	Worst	L1	L2	L3	L4	Worst		Spine	Hip	Forearm
Sagittal														
L1	1.00	0.90	0.86	0.88	0.91	0.96	0.89	0.83	0.86	0.90	0.91	0.40	0.38	0.30
L2	0.90	1.00	0.87	0.89	0.94	0.89	0.93	0.80	0.88	0.92	0.94	0.43	0.38	0.23
L3	0.86	0.87	1.00	0.86	0.93	0.86	0.86	0.94	0.85	0.91	0.92	0.40	0.41	0.19
L4	0.88	0.89	0.86	1.00	0.95	0.88	0.91	0.83	0.95	0.95	0.95	0.45	0.43	0.22
Worst	0.91	0.94	0.93	0.95	1.00	0.91	0.92	0.86	0.92	0.98	0.99	0.50	0.48	0.23
Axial														
L1	0.96	0.89	0.86	0.88	0.91	1.00	0.87	0.85	0.85	0.90	0.91	0.43	0.41	0.28
L2	0.89	0.93	0.86	0.91	0.92	0.87	1.00	0.83	0.93	0.95	0.94	0.47	0.45	0.22
L3	0.83	0.80	0.94	0.83	0.86	0.85	0.83	1.00	0.81	0.86	0.87	0.38	0.38	0.23
L4	0.86	0.88	0.85	0.95	0.92	0.85	0.93	0.81	1.00	0.94	0.94	0.42	0.46	0.13
Worst	0.90	0.92	0.91	0.95	0.98	0.90	0.95	0.86	0.94	1.00	1.00	0.49	0.48	0.24
Worst CT Scan HU	0.91	0.94	0.92	0.95	0.99	0.91	0.94	0.87	0.94	1.00	1.00	0.49	0.48	0.23
Worst DXA Score														
Spine	0.40	0.43	0.40	0.45	0.50	0.43	0.47	0.38	0.42	0.49	0.49	1.00	0.90	0.33
Hip	0.38	0.38	0.41	0.43	0.48	0.41	0.45	0.38	0.46	0.48	0.48	0.90	1.00	0.19
Forearm	0.30	0.23	0.19	0.22	0.23	0.28	0.22	0.23	0.13	0.24	0.23	0.33	0.19	1.00

these studies were brought in by patients as part of their existing pre-operative workup and came from smaller community centers that had differing protocols from a high volume, academic center, such as the one where this study was conducted. While the heterogenous imaging location may add variability to the study results, the data represent a real world spine surgery population; and therefore, adds to the generalizability of previously published literature on the topic. Additionally, the study population is heterogeneous with regard to gender, age, comorbidities, and medications. Again, the study population represents a real world spine surgery patient population which adds to the generalizability of the previously published DXA and CT HU concepts and correlations.

5. Conclusions

In conclusion, our study demonstrates that the gold standard of BMD measurement, DEXA scan, and a more recent modality, CT HU measurements, only maintain mild correlation while attempting to qualify the same parameter. Within the modality of CT HU measurement itself, there is a robust correlation between measurements in the axial or sagittal plane of the same vertebral body, which is a positive finding that can be effectively utilized in a clinical setting.

CRediT authorship contribution statement

Shivam N. Upadhyaya: Validation, Investigation, Data curation, Writing – original draft, Writing – review & editing, Visualization. **Charles H. Crawford:** Conceptualization, Validation, Investigation, Resources, Data Curation, Writing – review & editing, Visualization, Supervision. **Grant O. Schmidt:** Validation, Investigation, Data Curation, Writing – original draft, Writing – review & editing, Visualization. **Derek Arrington:** Validation, Investigation, Data Curation, Writing – original draft, Writing – review & editing, Visualization. **John R. Dimar:** Conceptualization, Validation, Investigation, Resources, Data Curation, Writing – review & editing, Visualization, Supervision. **Steven D. Glassman:** Conceptualization, Validation, Investigation, Resources, Data Curation, Writing – review & editing, Visualization, Supervision. **Jeffrey L. Gum:** Conceptualization, Validation, Investigation, Resources, Data Curation, Writing – review & editing, Visualization, Supervision. **Amer H. Ahmad:** Validation, Investigation, Data Curation, Writing – original draft, Writing – review & editing, Visualization. **Leah Y. Carreon:** Conceptualization, Methodology, Validation, Formal analysis, Investigation, Resources, Data Curation, Writing – review & editing, Visualization, Supervision, Project administration.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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