EDITOR'S CHOICE

Using Hounsfield Units to Assess Osteoporotic Status on Wrist Computed Tomography Scans: Comparison With Dual Energy X-Ray Absorptiometry

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Purpose Rates of evaluation and treatment for osteoporosis following distal radius fragility fractures remain low. As a subset of patients with these fractures undergo diagnostic computed tomography (CT) scan of the wrist, utilizing bone mineral density (BMD) measurements available with this imaging can be used to detect osteopenia or osteoporosis. This information may consequently prompt intervention to prevent a subsequent fracture. The purpose of this study was to determine if Hounsfield unit (HU) measurements at the wrist correlate with BMD measurements of the hip, femoral neck, and lumbar spine and to assess the ability of these HU measurements to detect osteoporosis of the hip.

Methods Forty-five female patients with distal radius fractures who underwent CT scan and dual energy x-ray absorptiometry scan as part of the management of their wrist fracture were identified. Bone mineral density measurements were made using the regional cancellous bone HU value at the capitate and compared with values obtained by a dual energy x-ray absorptiometry scan.

Results Hounsfield unit values at the capitate were significantly correlated with BMD and *t* scores at the femoral neck, hip, and lumbar spine. An HU threshold of 307 in the capitate optimized sensitivity (86%) and specificity (94%) for detecting osteoporotic patients.

Conclusions By demonstrating that capitate HU measurements from clinical CT scans are correlated with BMD and *t* scores at the hip, femoral neck, and lumbar spine, our data suggest that clinical CT scans should have a role in detecting osteopenia and osteoporosis. *(J Hand Surg Am. 2016;41(7):767–774. Copyright © 2016 by the American Society for Surgery of the Hand. All rights reserved.)*

Type of study/level of evidence Diagnostic III.

Key words Bone mineral density, distal radius fracture, dual x-ray absorptiometry, Hounsfield unit, osteoporosis.

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THE INCIDENCE OF OSTEOPOROTIC fragility fractures is expected to increase 2- to 4-fold in the next 30 years, which will potentially place a major burden on the health care system.[1–3] Numerous efforts have been made at the national level to focus on improving the identification and evaluation of high-risk individuals.[2] A history of a fragility fracture is one of the strongest risk factors for developing a subsequent fracture, and a fragility fracture of the wrist is associated

with a 5-fold increase in sustaining a vertebral fracture and a 3-fold increase in sustaining a hip fracture in the future.[4,5] Because fragility fractures of the wrist typically occur about 15 years prior to a hip fracture, it has been recommended that interventions be targeted to this group.[6–9]

Medical management of osteoporosis following distal radius fractures can effectively lower a patient's risk of developing a hip or vertebral fracture[10]; bisphosphonate therapy alone has been shown to reduce fracture risk by up to 70%.[11] However, only a fraction of patients who sustain a fragility fracture are diagnosed with osteoporosis, and less than 10% of those diagnosed are started on treatment.[12,13] The reason for the gap between evidence-based treatment guidelines and treatment rates remains unclear, although several barriers have been suggested and explored. For one, there is often confusion regarding which physician is responsible for treating osteoporosis following a fragility fracture.[12,14] Other barriers include the cost of medication and patient transportation issues.[15–17] Orthopedic surgeons who treat distal radius fractures are in a unique position to identify patients who could benefit from osteoporosis evaluation, and level I evidence indicates improved rates of evaluation and treatment when this is initiated by orthopedic surgeons.[12,18] Patients with distal radius fractures are a high-risk group that should be targeted for screening, but as few as 2.8% of women undergo a bone mineral density (BMD) test after sustaining a wrist fragility fracture.[6–9]

Measurement of BMD using dual energy x-ray absorptiometry (DEXA) remains the gold standard for the diagnosis of osteoporosis and is ideal for screening secondary to its minimal radiation exposure and low cost. The widely accepted World Health Organization (WHO) definition of osteoporosis is based on the DEXA *t* score, which is defined as the number of SDs by which the recorded bone density differs from a control value derived from the mean and SD of values in a young healthy population.[19] For patients who have not undergone DEXA screening, alternative methods for identifying those at risk may be readily available and should be considered.

There is mounting evidence in the literature that information about bone quality can also be ascertained via Hounsfield unit (HU) measurements obtained from diagnostic computed tomography (CT) scans.[20,21] An HU value is a standardized linear attenuation coefficient of tissue, based on a defined scale of 0 for water and −1,000 for air, that represents the density of tissue. Values are calculated from the following formula: $HU = ((\mu - \mu_w)/\mu_w) \times 1000$, with μ defined as the linear x-ray attenuation coefficient of the selected tissue and μ_w the attenuation coefficient of water.[22,23] Hounsfield unit measurements can be calculated from a region of interest (ROI) using most modern radiology imaging software without added costs or radiation.

Measuring HU from CT has generated accurate estimates of BMD in the spine.[20,22] In a recent study, patients with distal radius fractures had significantly lower HU measurements in wrist CTs than patients without distal radius fractures,[24] but to our knowledge, the relationship between HU measurements and DEXA scores has not yet been investigated in the wrist. Given that the vast majority of patients fail to obtain a DEXA scan after sustaining a fragility fracture of the wrist, establishing HU thresholds for the diagnosis of osteoporosis and osteopenia from wrist CT scans may have the potential to improve rates of osteoporosis treatment in this population.

The purpose of this study was to assess the ability of HU measurements of the capitate on clinical CT scans to detect osteoporosis or osteopenia of the hip. We chose hip BMD as our primary outcome because hip fracture risk prediction is determined by hip BMD,[20,25] and hip BMD is more predictive of future fractures than spine or peripheral BMD measures.[26–30] Bone mineral density and *t* scores at the femoral neck and lumbar spine were included as secondary outcomes. We hypothesized that HU measurements of the capitate on clinical CT scans would correlate with BMD measurements and *t* scores at the hip, femoral neck, and lumbar spine.

PATIENTS AND METHODS

Study cohort

Institutional review board approval was obtained for this retrospective case series. Inclusion criteria were presence of a distal radius fracture, female gender, and a DEXA scan within 12 months of the distal radius fracture. Nine hundred seven distal radius fractures were identified on CT scans archived in a picture archiving and communication system between 2005 and 2015 at our institution. Fifty-three of these 907 fractures underwent a DEXA scan within 12 months of the distal radius fracture. Of the 53 distal radius fractures that met initial inclusion criteria, 3 were excluded on the basis of incomplete DEXA results. The study was limited to females because average HU measurements vary based on gender.[23,24] Thus, the 5 male patients were also excluded from the study. Our final cohort consisted of 45 female patients who had a diagnostic CT scan documenting a distal radius fracture between 2005 and 2015 and a DEXA within 12 months of that diagnosis.

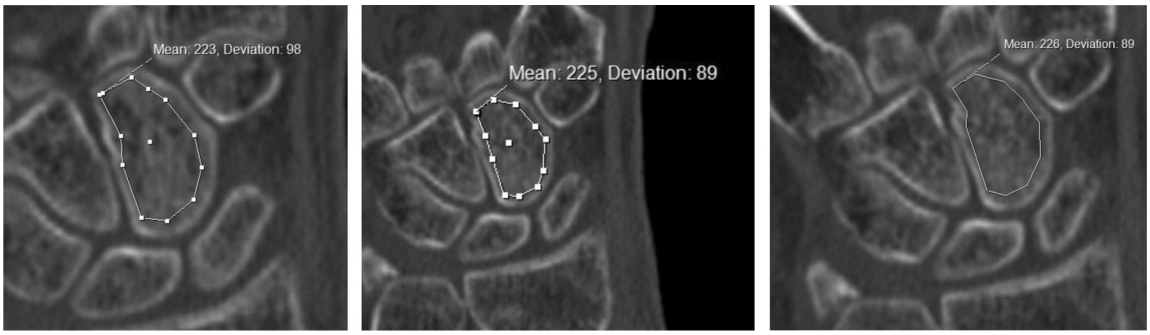

FIGURE 1: Images demonstrate the technique for obtaining regional HU values from cancellous portions of the capitate. Coronal images were used to obtain measurements within the capitate, and a mean of 3 slices was used in the analysis. Cancellous bone density was assessed with the use of standard radiology software.

Hounsfield unit methodology

Unenhanced CT of the wrist was performed without contrast in 1 of 2 institutional 16-multi-detector CT scanners (MX8000; Philips Healthcare, Andover, MA). According to previously published methodology,[22,24] the ROI tool in Sectra IDS7 picture archiving and communication system was utilized to calculate HU values within the capitate. The capitate was selected, as opposed to the distal radius metaphysis, to minimize any effects of the fracture site on the HU measurement and to facilitate consistency in HU measurements based on its regular and consistent shape. Severe distal radius fractures with significant comminution often have areas of bone loss, producing artificially low HU measurements.

Regions of interest were outlined on 3 separate coronal images of the capitate, and a mean of 3 slices was used in the analysis, as shown in Figure 1. All measurements were isolated to cancellous portions of bone with avoidance of cortical regions, consistent with previously optimized methodology reported in the lumbar spine[22] and distal radius.[24] Two orthopedic surgeons ascertained HU measurements independently, and their values were averaged.

Statistical analysis

Continuous variables were reported as means and SDs and compared using a 2-tailed Student *t* test. Interobserver reliability of HU measurements was assessed using the Pearson product-moment correlation coefficient. A value of greater than 0.8 is considered "excellent" interrater correlation,[31] although lower values have been reported as acceptable in the context of osteoporosis screening.[32] A 2-tailed Pearson r analysis was used to assess the correlation both between HU and BMD as well as HU and *t* scores. The 2 outcomes of interest, BMD and *t* scores, are correlated but we believe it appropriate to frame all CT-based results in terms of the DEXA *t* scores because this represents the necessary reference standard as defined by WHO, and *t* scores are commonly used in clinical practice in determining treatment stratification.[33,34] However, because data are lost by converting continuous BMD data into categorical data, we also reported the association between HU and BMD, consistent with previous investigations on the subject.[22–24,32,35]

A receiver-operating characteristic curve was used to identify thresholds that would yield high sensitivity (~ 90%), high specificity (~ 90%), or a balance between the 2 for distinguishing osteoporosis from nonosteoporosis. These HU threshold cutoff values relevant to the detection of osteoporosis were assessed using a chi-square test.

RESULTS

Interobserver reliability

Interobserver reliability of the measurement of HU at the capitate was excellent ($r = 0.918$; $P < .05$).

Correlation of DEXA and HUs

Within our institution, 907 distal radius fractures were identified on CT scans, and 50 of these patients (45 female) underwent DEXA scans within 12 months of the fracture (5.5%). The subjects underwent a wrist CT as part of the work-up for a distal radius fracture and the DEXA scan was obtained within 12 months of the CT scan. Computed tomography scans are often obtained at our institution for preoperative planning prior to osteosynthesis, with the most common reason for ordering a CT scan being fracture (n = 26; 57.8%), followed by joint pain (n = 17; 37.8%), as determined by International Classification of Disease-Ninth Revision codes. The mean age was 66.9 (range, 34–84 years). The HU values for the 45 subjects ranged from 78 to 547 (mean, 347.2 ± 87.99). Dual energy x-ray absorptiometry *t* scores of the hip ranged from 0.4 to −3.2, (mean, −1.36 ± 0.97), and BMD

TABLE 1. Mean BMD and *t* Scores at Hip, Femoral Neck, and Lumbar Spine as Measured by DEXA

	Mean BMD (g/cm^2) ± SD (Range)	Mean *t* Score ± SD (Range)
Hip	0.769 ± 0.14 (0.434–0.989)	−1.36 ± 0.965 (0.4 to −3.2)
Femoral neck	0.663 ± 0.11 (0.434–0.806)	−1.78 ± 0.807 (−0.6 to −3.4)
Lumbar spine	0.875 ± 0.209 (0.581–1.802)	−1.43 ± 1.299 (1.0 to −3.8)

TABLE 2. Correlation between HU Measurement at the Capitate and BMD and *t* Scores at Hip, Femoral Neck, and Lumbar Spine

	HU Capitate Versus Hip		HU Capitate Versus Femoral Neck		HU Capitate Versus Lumbar Spine	
	BMD	*t* Score	BMD	*t* Score	BMD	*t* Score
Pearson r	0.64	0.65	0.69	0.61	0.47	0.45
95% confidence interval	0.423–0.784	0.441–0.793	0.495–0.817	0.383–0.765	0.209–0.674	0.179–0.660
R^2	0.406	0.423	0.475	0.37	0.225	0.204
P value	< .001	< .001	< .001	< .001	.001	.0021

ranged from 0.43 to 0.99 g/cm^2 (mean, 0.77 ± 0.14 g/cm^2). Dual energy x-ray absorptiometry *t* scores of the femoral neck ranged from −0.6 to −3.4 (mean, −1.78 ± 0.81), and BMD ranged from 0.43 to 0.81 g/cm^2 (mean, 0.66 ± 0.11 g/cm^2). Dual energy x-ray absorptiometry *t* scores of the lumbar spine ranged from 1 to −3.8, (mean, −1.43 ±1.30), and BMD ranged from 0.58 to 1.80 g/cm^2 (mean, 0.88 ± 0.21 g/cm^2). The DEXA *t* scores and BMD by location are summarized in Table 1.

Hounsfield unit values were positively correlated with BMD as measured at the hip ($r^2 = 0.406$; $P < .05$), femoral neck ($r^2 = 0.475$; $P < .05$), and lumbar spine ($r^2 = 0.225$; $P = .05$), as shown in Table 2 and Figure 2. Hounsfield unit values were also associated with *t* scores of the hip ($r^2 = 0.423$; $P < .05$), femoral neck ($r^2 = 0.370$; $P < .05$), and the lumbar spine ($r^2 = 0.204$; $P = .05$), as summarized in Table 2 and Figure 3.

On the basis of WHO criteria, subjects were stratified according to *t* scores as normal (≥ −1.0), osteopenic (between −1.0 and −2.5), or osteoporotic (≤ −2.5) based on BMD measurements at the hip on DEXA. In our cohort, 15.6% (n = 7) of the patients were osteoporotic at the hip, 46.7% (n = 21) were osteopenic at the hip, and 37.8% (n = 17) had normal BMD at the hip based on DEXA scans obtained within 12 months of the diagnostic CT scan. Average HU measurements and BMD for each group are summarized in Tables 3 and 4, respectively.

An HU threshold of 307 in the capitate optimized sensitivity (86%) and specificity (94%) for discerning patients with osteoporosis, defined as a *t* score below −2.5, from patients with a normal *t* score. A CT attenuation threshold less than 378 HU was more than 95% sensitive and a threshold of less than 284 HU was more than 90% specific for distinguishing osteoporotic patients from those with a normal BMD.

DISCUSSION

The results of our study demonstrate that HU measurements of the capitate on clinical CT scans are significantly correlated with BMD measurements and *t* scores at the hip, femoral neck, and lumbar spine. In addition, we identified a minimum threshold of 307 HU in the capitate, which was diagnostic for osteoporosis of the hip with a sensitivity of 86% and specificity of 94% in our cohort.

The moderate correlation reported in our study between capitate HU values and hip BMD and *t* score ($P < .05$; $r^2 = 0.406$ and 0.423, respectively) is consistent with associations reported elsewhere in the literature. Schreiber et al[24] identified a correlation of similar magnitude between lumbar spine HU measurements and lumbar spine BMD and *t* score. Pervaiz et al[35] also reported a moderate correlation between HU measurements of the proximal humerus and femoral neck BMD and *t* score. Finally, moderate correlations were also reported by Lee et al[32] between HU measurements and BMD in the same anatomical region at the following locations: L1, L2, L3, L4, femoral neck, and greater trochanter.

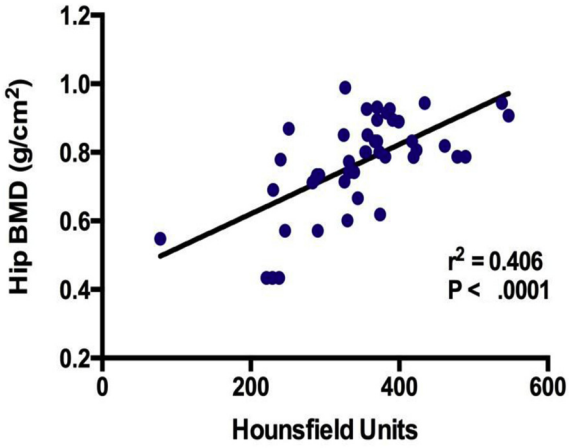

FIGURE 2: Scatter plot shows the correlation between HUs obtained from CT and BMD obtained from DEXA scans of the hip of 45 subjects. A significant correlation was found ($r^2 = 0.406$; $P < .001$).

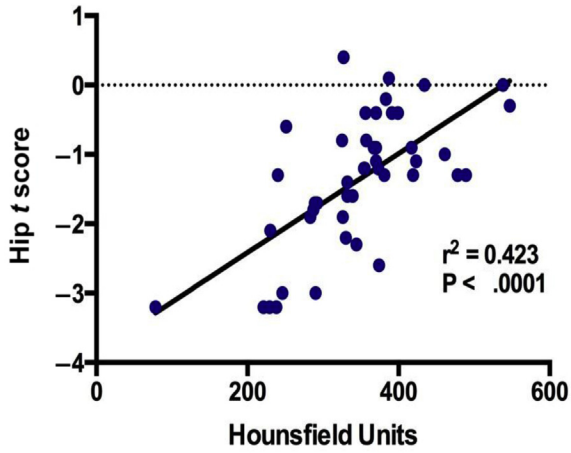

FIGURE 3: Scatter plot shows the correlation between HUs obtained from CT and *t* scores obtained from DEXA scans of the hip of 45 subjects. A significant correlation was found ($r = 0.423$; $P < .001$).

TABLE 3. Mean and SD of HU Measurements in Normal, Osteopenic, and Osteoporotic Subjects

	t Score	Mean HU Capitate ± SD (Range)
Normal	≥ −1.0	392.94 ± 73.03 (78−374)
Osteopenic	< −1.0 or > −2.5	346 ± 67.53 (230−489)
Osteoporotic	≤ −2.5	239.43 ± 88.71 (251−547)

The HU threshold identified in our study (307) that optimized sensitivity and specificity for the diagnosis of osteoporosis is also comparable with thresholds reported elsewhere in the literature. Our threshold is slightly higher than that reported by Schreiber et al[24] at the distal radius (248 and 218 in males and females, respectively), but their cutoff optimized sensitivity and specificity for distinguishing fracture patients from controls whereas the threshold in the present study optimized sensitivity and specificity for identifying patients with osteoporosis from those with a normal BMD. Similar to normative values for BMD as measured by DEXA, the normative values for HU will be different depending on the anatomical site. For example, the study by Lee et al[32] reported the HU threshold for osteoporosis at the femoral head as 296, whereas the threshold reported for the distal tibia is 122.

At our institution, 31% of patients with distal radius fractures undergo a diagnostic CT scan,[24] and only 5% of this subset of patients obtains a DEXA scan within 12 months of their injury. This finding is consistent with a review of a large managed-care database, which revealed that only 2.8% of women over the age of 50 who had a distal radius fracture subsequently underwent a DEXA scan,[6,9] and confirms that patients with wrist fractures are not routinely undergoing formal osteoporosis screening. The results of this study demonstrate that a patient's bone quality can be inferred based on a diagnostic imaging study that may already be available. Because HU values measured by wrist CT correlate with BMD as determined by DEXA, orthopedic surgeons have another tool for determining the patients at high risk who require further evaluation and intervention for osteoporosis.

Dual energy x-ray absorptiometry is currently the gold standard for the diagnosis of osteoporosis, but when a CT scan has already been obtained during the work-up of a distal radius fracture, there is information relating to the patient's bone quality that is readily available to clinicians by measuring HU.[20−22] The retrieval of BMD data available from CT scans requires no additional cost, patient time, equipment, or radiation exposure.[20,36] The cost-effectiveness of this opportunistic screening method has not yet been explored, but it has the potential to yield substantial cost savings through increasing detection of osteoporosis, with subsequent appropriate treatment to reduce fracture risk, and reducing the number of normal DEXA studies.[20,33]

To date, several methods to improve the detection of osteoporosis have been tested. Rhee and Baek[37]

TABLE 4. Mean and SD of BMD Measurements in Normal, Osteopenic, and Osteoporotic Subjects

	t Score	Mean BMD Hip (g/cm^2) ± SD (Range)	Mean BMD Femoral Neck (g/cm^2) ± SD (Range)	Mean BMD Lumbar Spine (g/cm^2) ± SD (Range)
Normal	≥ −1.0	0.889 ± 0.049 (0.819–0.989)	0.736 ± 0.046 (0.646–0.781)	1.062 ± 0.208 (0.843–1.802)
Osteopenic	< −1.0 or > −2.5	0.757 ± 0.066 (0.601–0.931)	0.656 ± 0.086 (0.525–0.806)	0.783 ± 1.073 (0.627–0.945)
Osteoporotic	≤ −2.5	0.516 ± 0.079 (0.434–0.619)	0.510 ± 0.127 (0.434–0.789)	0.696 ± 0.145 (0.581–0.943)

employed CT-osteoabsorptiometry to obtain HU measurements at the distal radius in 80 postmenopausal women and, consistent with the findings of the present study, identified an association between these measurements and BMD at the femoral neck and lumbar spine. In the protocol used by Rhee and Baek,[37] digital images of distal radii were scanned by conventional CT, reformatted to produce the desired slice, cropped to include the ROI, and then processed to create a 3-dimensional object. This object was then converted into a 2-dimensional densiometric map from which the authors derived tomographic patterns and HU measurements. Whereas the methods proposed by Rhee et al[37] require additional software not readily available to most orthopedic surgeons, the method described in the present study consists of only 1 step in the normal imaging software used to view images: drawing an ROI on diagnostic CT scans.

Investigators have also identified relationships between BMD and quantitative CT scans of the wrist,[38–40] but the need for calibration phantoms in this methodology precludes its use in most clinical settings, particularly at the time of injury. An association between BMD and wrist magnetic resonance imaging has also been established,[41] but this technique, like CT-osteoabsorptiometry, has limited applicability outside of a research setting. In short, HU measurements also offer distinct advantages to each of these other instruments, because they are readily available without added costs, software, digital imaging processing, or the use of calibration phantoms.[22]

Standard wrist radiographs have also been used to evaluate BMD in 2 studies.[42,43] In the first, a cadaveric study by Rausch et al,[42] cortical thickness of the distal radius measured on standard anteroposterior radiographs was shown to correlate with DEXA measurements of radius BMD. In the second, Webber et al[43] reviewed posteroanterior radiographs of 61 females with a distal radius fracture to obtain distal radius cortical measurements. They reported a moderate correlation between bicortical thickness and femoral neck BMD, but no association between cortical thickness and lumbar spine BMD was identified. The applicability of this technique in routine clinical practice is unknown because these measurements are affected by patient positioning, fracture location, and rotation; for example, in the study by Webber et al,[43] 15.2% of eligible subjects were excluded because measurements could not be obtained on the injury radiographs. However, with validation of radiographic parameter measurement technique and location, these data demonstrate that routine radiographs may also have a role in bone quality assessment.

The present study has several limitations. First, the data obtained for correlations between the HU value and DEXA were from females with a distal radius fracture. In general, these patients were older (mean age, 66.8 years) and had decreased BMD (mean *t* scores, −1.78 and −1.36 at the femoral neck and hip, respectively). However, this limitation does not affect our conclusion, because our aim was to assess the ability of opportunistic CT scans to diagnose hip osteoporosis in female patients with a fragility fracture of the wrist. Second, the time between CT and DEXA (minimum, 1 year) may have also influenced the accuracy of the results. Furthermore, because the majority of women with a distal radius fracture do not obtain a DEXA scan, our cohort may not accurately reflect the incidence of osteoporosis in all women who sustain a distal radius fracture. However, the rates of osteoporosis (15.6%) and osteopenia (46.7%) in our cohort are comparable with that found in other studies.[7,9] It is also possible that some women were started on osteoporosis treatment following the distal radius fracture, which may have affected the DEXA results. Third, the HU values were obtained from CT scans obtained from 1 of 2 institutional CT scanners, and it is possible that a different CT scanner or different configurations may produce minor differences in measurements. However, we analyzed the correlation between bone attenuation on CT scans to DEXA values. Thus, we believe that any difference in CT scanners would have little influence on our results. Finally, we recognize that the results of this study will apply only to a subset of patients with distal radius fractures who have undergone CT scans. Given that a minority of patients undergo CT for the management of a distal radial fracture, it is unknown whether our fracture cohort is truly representative of the larger distal radial fracture cohort. Furthermore, because CT scans are often employed to evaluate intra-articular distal radius fractures[44–46] or for preoperative planning,[47] our results may not extrapolate to the general population. We do not propose that CT scans should be obtained on distal radius fractures that are not necessary for fracture management to assess bone quality. However, when a CT scan is obtained for other indications, our results demonstrate that information about bone quality is readily available and may be used to identify patients who may benefit from an osteoporosis evaluation and possible intervention.

By demonstrating that HU measurements from clinical CT scans at the capitate are correlated with BMD and *t* scores at the hip, femoral neck, and lumbar spine, our data suggest that clinical CT scans present an opportunity to detect osteopenia and osteoporosis. Furthermore, our results suggest that intervention for osteoporosis should be considered in female patients with an HU measurement below 307 at the capitate.

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