EDITOR'S CHOICE

Assessing Bone Mineral Density Using Radiographs of the Hand: A Multicenter Validation

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Purpose Osteoporosis and fragility fractures incur substantial costs to quality of life and global health care systems. The current gold standard for quantifying bone density is dual-energy X-ray absorptiometry. Our hypothesis is that bone density can be accurately predicted with a simpler method using plain radiographs of the hand.

Methods This retrospective cohort study was undertaken in two centers in the United Kingdom, where the second metacarpal cortical percentage (2MCP) scores were calculated from radiographs. This study included patients who had sustained a distal radius fracture between 2020 and 2022 and had received both a posteroanterior radiograph of the hand and a dual-energy X-ray absorptiometry scan within 12 months of their radiograph and fracture. The Pearson correlation coefficient was calculated to determine the correlation between 2MCP scores and t-scores of the femoral neck on dual-energy X-ray absorptiometry scans.

Results Of the 188 patients, the 2MCP score significantly correlated with bone density t-scores of the femoral neck. A 2MCP score <50% demonstrated 100% sensitivity and 100% specificity for differentiating osteoporotic from normal subjects, whereas a 2MCP score <60% demonstrated 94.4% sensitivity and 83.0% specificity in differentiating osteopenic from normal subjects.

Conclusions These data confirm that the likelihood of osteoporosis being present can be determined via the 2MCP score. *(J Hand Surg Am. 2023;■(■):■−■. Copyright © 2023 by the American Society for Surgery of the Hand. All rights reserved.)*

Type of study/level of evidence Diagnostic 1b.

Key words Fragility fracture, DEXA, Distal radius fracture, Bone health.

IN THE CONTEXT OF AN AGING population, fragility fractures represent a substantial financial burden on global health care systems. Fragility fractures of the distal radius, hip, or vertebrae are common and cost the UK National Health Service £4.4 billion ($5.6 billion USD) per year.[1] Globally, osteoporosis contributes to more than 8.9 million fractures annually[2] and is predicted to increase 2-fold to 4-fold by 2040.[3] These fractures cause severe pain, disability, and reduced quality of life, and among those who

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incur hip fractures, 26% will die within 12 months.[4,5] It is well known that screening and early treatment of osteoporosis reduces future risk of fragility fractures.[6,7] Therefore, a global incentive exists to improve bone health and prevent fractures, reducing costs to quality of life and health care systems.

Osteoporosis is a systemic disease defined by a reduction in bone mass and disruption in bone microarchitecture, resulting in reduced bone mineral density (BMD).[8] The World Health Organization definition of osteoporosis is based on a reduction in BMD compared with a young, healthy population, and the current gold standard for quantifying BMD is dual-energy X-ray absorptiometry (DEXA).[7] Patients at "high risk" of developing osteoporosis or those with typical osteoporotic fractures (distal radius, hip, and vertebra) should be referred for DEXA to measure the BMD of the femoral neck because of its high predictive value for fracture.[9] The scan quantifies BMD, generating a "t-score" based on a patient's number of standard deviations away from the bone density of the normal population.

The effects of osteoporosis are diffuse within the appendicular and axial skeletons, thus enabling a global calculation of bone density based on one anatomical region, typically taken at the femoral neck with a DEXA. We hypothesize that BMD can be measured with a simpler method than DEXA using plain radiographs of the hand. The second metacarpal cortical percentage (2MCP) score has been shown to correlate with BMD in a single-center study in the United States.[10] This multicenter study aimed to validate the 2MCP score in predicting BMD using a radiograph of the hand in two cohorts with differing demographics—an urban population of higher socioeconomic status and a suburban population with lower socioeconomic status.

METHODS

Study cohort

A retrospective cohort study was undertaken in the following two UK centers: one center was an urban sample from a high socioeconomic background[11] and the second center was a suburban cohort that, based on income, employment, and education, was considered less affluent.[12] These two centers were chosen to create a generalizable study sample representative of the UK population. Patients were included in the study who had sustained a distal radius fracture between 2020 and 2022 and had received both a posteroanterior (PA) radiograph of the hand and a DEXA scan within 12 months of their radiograph. Excluded patients included those with any inability to assess their radiograph (eg, because of the overlying cast material and/or hardware), those with incomplete DEXA results, and those with previous hip arthroplasty.

Patient records were examined for demographics and injury details with anonymized radiographs from local electronic imaging systems. Institutional review board approval was granted at both sites.

Second metacarpal cortical percentage calculation

The 2MCP score is calculated from the mid-diaphyseal cortical percentage of the second metacarpal on a true PA radiograph of the hand.[10] All radiographs followed a standard protocol with the digits in extension. The study used digital radiographs that were then photographed through a smartphone application (Harborlight Solutions LLC). This application enables a user to calculate the 2MCP score after a short instructional demonstration. First, the transverse diameter of the second metacarpal is calculated at the isthmus, the narrowest part (A). Then, a second measurement is taken at this same level of the intramedullary/cancellous component of the total diameter (B). After these two calculations are taken, the smartphone application calculates the 2MCP score through the formula $[(A-B)/A] \times 100$, generating a cortical percentage score (Fig. 1). The score takes less than 60 seconds to calculate. This calculation can also be calculated simply using the measurement function on any electronic image viewing software.

All scores were calculated by an independent, blinded assessor and then compared with the DEXA t-score of the femoral neck. Assessors were blind to patient demographics and DEXA t-scores. The same DEXA scanner was used in both cohorts—the Harborlight Discovery DEXA System (Harborlight Solutions LLC).

Statistical analysis

Subjects were stratified into normal, osteopenic, and osteoporotic based on the DEXA t-score as per the World Health Organization criteria.[13] We calculated thresholds that optimized sensitivity and specificity for discerning osteopenic and osteoporotic BMD compared with normal BMD—based on those thresholds used for the single-center study that validated 2MCP in the United States.[10] As in the US study, osteopenia was defined as a 2MCP threshold of less than 60% (giving an optimized sensitivity of 88% and specificity of 60% for discerning osteopenic

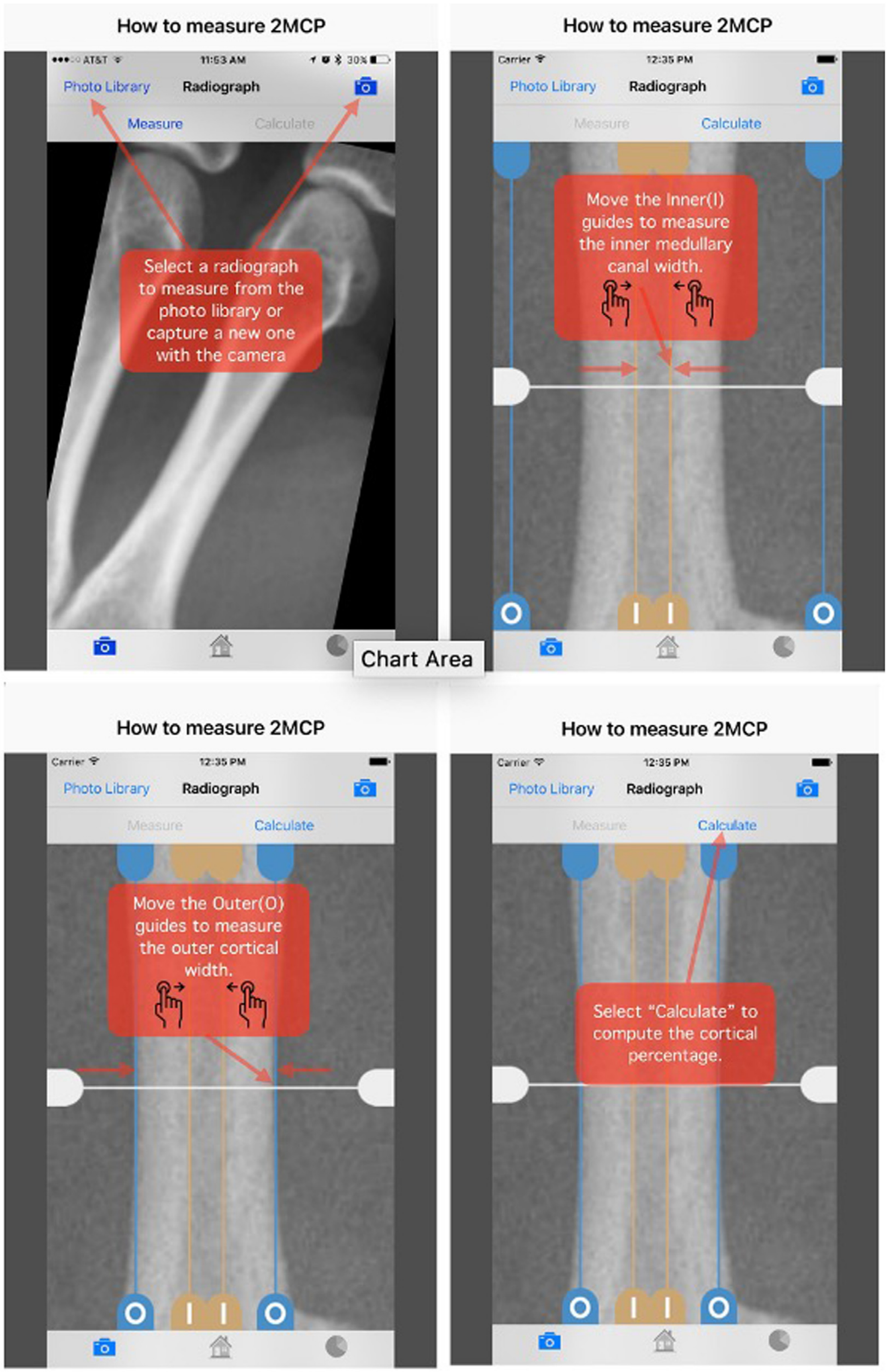

FIGURE 1: Calculating the 2MCP score using BoneGauge application.

from normal patients), and osteoporosis was defined as a 2MCP threshold of less than 50% (100% sensitivity and 91% specificity for differentiating osteoporotic from a normal subject).[10]

Following this, a 2-tailed Pearson correlation coefficient was calculated to determine the correlation between 2MCP scores and t-scores of the femoral neck on DEXA scans.

TABLE 1. Demographics of Study Participants

Demographics	Urban Cohort	Suburban Cohort	Pooled
Number of patients	88	100	188
Age (y; mean)	64 (50−80)	72.1 (49-90)	68.1 (49−90)
Male (%)	11 (12.5)	8 (8)	19 (10.1)
Female (%)	77 (87.5)	92 (92)	169 (89.9)
Interval between radiograph and DEXA (d)	83 (5−264)	88 (12-255)	86 (5−264)
2MCP (%)	54.3 (30.7−76.1)	50.7 (25.0-76.7)	52.4 (25.0−76.7)
t-score BMD	−1.6 (−3.6 to 0.4)	−1.7 (−3.7 to 1.5)	−1.6 (−3.7 to 1.5)
Normal BMD, n (%)	27 (30)	20 (20)	47 (25.0)
Osteopenic BMD, n (%)	46 (52)	62 (62)	108 (57.4)
Osteoporotic BMD, n (%)	15 (17)	18 (18)	33 (17.6)

RESULTS

A preliminary search identified 196 patients in total from both centers. Within both cohorts, three were excluded due to overlying cast material; four were excluded due to the lack of a PA radiograph, and one was excluded due to incomplete DEXA results. This left two cohorts of patients: one consisted of 88 patients and one of 100 patients, leaving a final pooled cohort of 188 patients.

Among the two cohorts comprising 88 (urban cohort) and 100 (suburban area) patients, respectively, the demographics are summarized in Table 1. The mean ages were 64.0 and 72.1 years, respectively, and there was a female predominance within both the urban cohort ($n = 77/88$, 87.5%) and the suburban cohort ($n = 92/100$, 92%). The median time interval between the radiograph and the DEXA scan was 86 days (range 5−255 days) among the pooled cohorts.

The mean MCP scores in the urban cohort were 54.3 ± 10.5% (range 30.7−76.1) and 50.7 ± 9.6% (range 25.0−76.7) for the suburban cohort. The pooled data revealed a mean average 2MCP score of 52.4 ± 10.2% (range 25.0−76.7). The mean DEXA t-scores (femoral neck) of the urban cohort were −1.6 ± 0.9 (range −3.6 to 0.4) and −1.7 ± 1.0 (range −3.7 to 1.5) for the suburban cohort. When pooled, the patients had an average t-score of −1.6 ± 0.9 (range −3.7 to 1.5).

The 2MCP score correlated with the BMD t-score at the femoral neck in both the urban ($r^2 = 0.81$ $P < .05$), suburban ($r^2 = 0.82$, $P < .05$), and pooled cohorts ($r^2 = 0.81$, $P < .05$; Figs. 2−4). Within the pooled cohort, a 2MCP score of less than 50% demonstrated 100% sensitivity and 100% specificity for differentiating osteoporotic from normal subjects. A 2MCP score of less than 60% demonstrated 94.4% sensitivity and 83.0% specificity for differentiating osteopenic from normal subjects.

DISCUSSION

This multicenter study validates the 2MCP score in predicting low bone density from radiographs of the hand, replicating the original findings of a sample from the United States. Based on the above results, patients with a 2MCP score of less than 60% should be tested for metabolic bone disease and those with a 2MCP score of less than 50% are at a high risk of having osteoporotic BMD.

Calculating global bone density from the cortical thickness of specific bony anatomical regions on radiographs has been well documented. Sectra OneScreen (Sectra AB) uses digital X-ray radiogrammetry to estimate distal radius BMD from the second to the fourth metacarpal cortical bone thickness and bone width alongside mammography. However, this software package requires subscription at substantial costs to the health care provider alongside extensive training to carry out and interpret the scan results. Webber et al[14] showed that bicortical radial thickness correlated with DEXA femoral bone density in 80 women with distal radius fractures; however, these measurements require more intricate knowledge of electronic imaging systems, making them less accessible to some health care professionals. Handa et al[15] demonstrated that proximal humerus cortical thickness, calculated from shoulder radiographs, also correlated with DEXA bone density. In a cadaveric study of 54 upper limbs, Schmidutz et al[16] found that humeral cortical bone

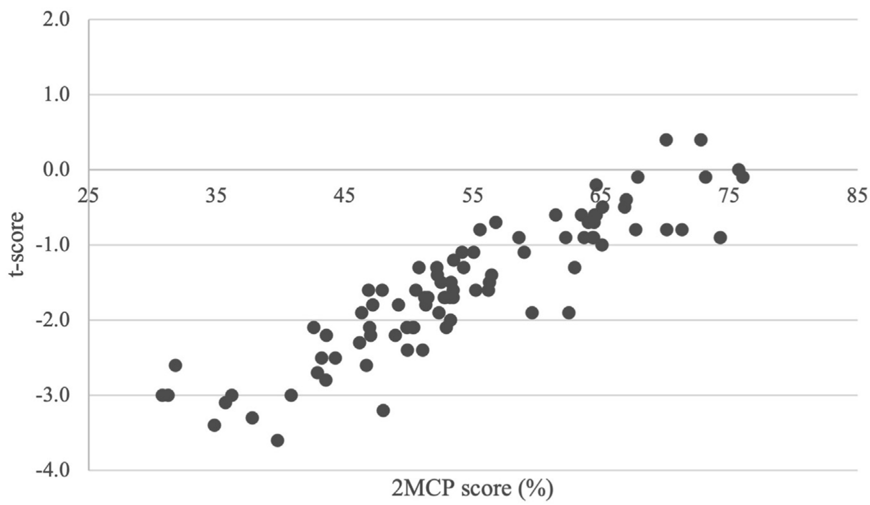

FIGURE 2: Urban cohort: positive linear correlation is observed between 2MCP and BMD t-scores at the femoral neck, $r^2 = 0.81$ $P < .05$.

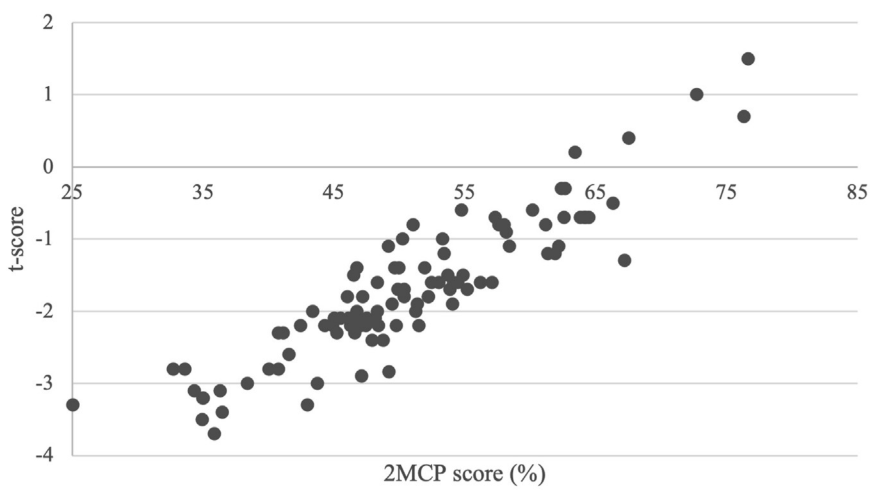

FIGURE 3: Suburban cohort: positive linear correlation is observed between 2MCP and BMD t-scores at the femoral neck, $r^2 = 0.82$ $P < .05$.

thickness correlated with humeral and distal radial BMD on DEXA. Osteoporosis is a systemic disease that affects the entire appendicular skeleton; therefore, a focused diagnostic investigation of a particular bony anatomical region can act as a surrogate marker for global bone density.

The implications of the findings of this study are threefold. First, we have calculated the local cost of a plain radiograph of the hand to be less than $7 USD, compared with approximately $60 USD for a DEXA scan.[17] Even allowing for a slight difference in cost between centers, this has considerable cost-saving potential in screening for metabolic bone disease. Second, a low 2MCP score (eg, <50%) may negate the need for further imaging, thereby reducing cumulative radiation exposure to patients. Third, the results can be calculated from radiographs already taken of the hand at the time of their initial assessment in the emergency department. In this way, bone density can be calculated by anyone who is able to digitally view the radiograph. This further reduces the costs because no further scans, radiologists, or specialist equipment are required to interpret the results. The patient does not need to return for a DEXA at a later appointment. Thus, screening of bone density can be performed in emergency departments for all patients who have a radiograph of the hand—one of the most common diagnostic investigations conducted each year. This could enable prompt referral for the early treatment of osteopenia and osteoporosis, with the aim of preventing fragility fractures and their impact on disability and quality of life.

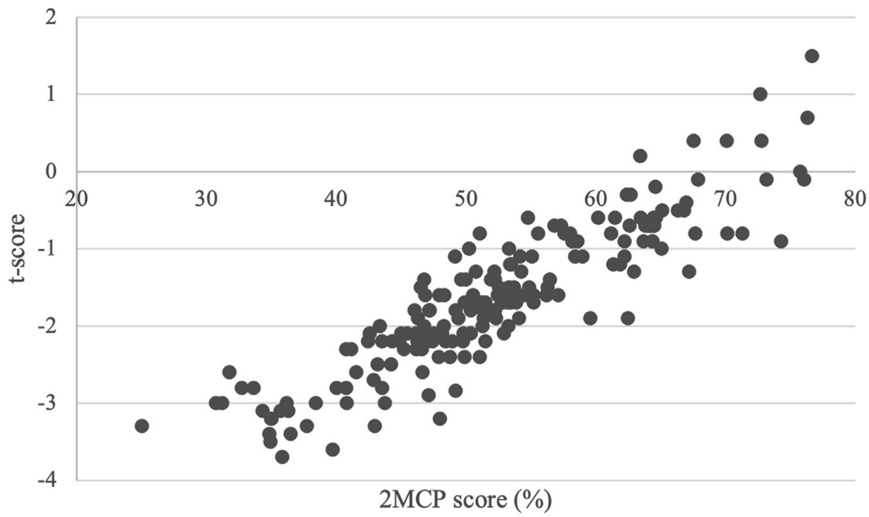

FIGURE 4: Pooled data: positive linear correlation is observed, $r^2 = 0.81$, $P < .05$.

Limitations to this study exist. This is a retrospective study of data collected from radiological investigations alone. During the selection of study participants, those with instrumented hips were excluded; this may have introduced selection bias because patients in whom internal fixation was used as treatment may demonstrate fractures of a certain severity or type. Second, the large time interval between the radiograph and the DEXA scan in some patients may have been associated with altered bone metabolism secondary to injury and immobilization, possibly affecting the validity of the observations.

The participants of this study had a strong female preponderance (89.9%) with an average age of 68.1 years, and therefore, this makes the results applicable to those at highest risk of fragility fractures—postmenopausal women.[18] With only 19 men, these data are less generalizable to men; however, this reflects the real-world cohort of patients who sustain fragility fractures. Unfortunately, a paucity of data also exists including young patients who undergo DEXA scanning, presumably because of their low fragility fracture risk. The addition of younger participants with a stronger male preponderance could increase the generalizability of these results.

The patients in the study had all sustained distal radius fractures, and therefore, in this high-prevalence sample, the performance characteristics of a medical test are likely to be spuriously increased. However, the correlation observed is made to a well-accepted reference standard, DEXA. Furthermore, it has been shown that the occurrence of a distal forearm fracture convincingly predicts future osteoporotic fractures.[19] Therefore, it is important to identify promptly and stratify those at a high risk of fractures to initiate treatment.

Further work into 2MCP should include the correlation of the score with the severity of osteoporosis. Moreover, with further work, it may be possible to initiate osteoporosis prevention therapy directly after the 2MCP calculation, negating the need for a DEXA scan.

The 2MCP score is a simple, low-cost tool to calculate BMD using a plain radiograph of the hand. Dual X-ray absorptiometry is the current reference standard for determining BMD, but we believe that the results from this multicenter validation study support the everyday use of the 2MCP score in risk stratification of patients for osteopenia and osteoporosis.

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