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ORIGINAL ARTICLE

Second metacarpal cortical percentage and psoas muscle index in predicting loss of reduction after non-operative treatment of distal radius fractures in adult women

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ABSTRACT

Objectives: This study aims to investigate whether second metacarpal cortical percentage (2MCP) and psoas muscle index (PMI) were associated with loss of reduction after closed reduction and cast immobilization.

Patients and methods: A total of 91 adult female patients with distal radius fractures (DRFs) treated with closed reduction and cast immobilization between January 2014 and June 2025 were retrospectively analyzed. Patients with standardized serial radiographs and lumbar computed tomography (CT) performed within ± 3 months of injury were included. Clinical characteristics, AO/OTA fracture type, Lafontaine instability criteria, lumbar CT densitometry T-scores, 2MCP, and PMI were evaluated. Loss of reduction was defined radiographically during follow-up. Multivariate logistic regression was performed using predefined cut-off values, and receiver operating characteristic (ROC) curve analysis was used to explore cut-off values for 2MCP and PMI.

Results: The mean age was 63.0 ± 8.2 (range, 44 to 84) years. Loss of reduction occurred in 23 (25.3%) patients. In group comparisons, AO/OTA Type C fracture pattern, Lafontaine instability, CT densitometry-defined osteoporosis, 2MCP-defined osteoporosis, and low PMI were more frequent among patients with loss of reduction. In the multivariate analysis, 2MCP-defined osteoporosis was independently associated with loss of reduction (adjusted OR = 7.22; 95% CI: 1.16-45.06; p = 0.034). Low PMI was also independently associated with loss of reduction (adjusted OR = 25.52; 95% CI: 5.33-122.14; p < 0.001). The ROC curve analysis identified cut-off values of 48% for 2MCP and 3.65 for PMI.

Conclusion: Our study results showed that 2MCP-defined osteoporosis and low PMI were independently associated with loss of reduction after non-operative treatment of DRFs in female patients. These imaging-based parameters may support exploratory risk stratification.

Keywords: Bone mineral density, distal radius fractures, metacarpal bones, osteoporosis, psoas muscles, sarcopenia.

Distal radius fractures (DRFs) are among the most common fractures of the upper extremity and account for a substantial proportion of orthopedic trauma cases worldwide.[1,2] Their incidence is particularly high in older adults, particularly women, largely due to age-related bone fragility and the high prevalence of osteoporosis, making DRFs an important public health concern in this population.[3,4] These fractures typically result from low-energy trauma, such as a fall from standing height, in older adults with reduced bone mineral density (BMD), whereas high-energy mechanisms are more commonly observed in younger patients.[5-7] In addition to their immediate functional consequences, DRFs are increasingly recognized as sentinel events in the fragility fracture cascade and may precede more serious osteoporotic fractures, particularly hip and vertebral fractures.[8,9] Consequently, assessment and management of underlying skeletal fragility in patients with DRFs have become important components of contemporary orthopedic care.[10]

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Despite advances in surgical fixation techniques, closed reduction and cast immobilization remain widely used for selected DRFs, particularly in older adults. However, loss of reduction continues to represent a common and clinically important limitation of non-surgical treatment.[1,3,4]

Loss of reduction remains one of the major challenges in the non-surgical management of DRFs, as an initially acceptable reduction may gradually deteriorate during follow-up despite appropriate immobilization.[3,10] Lafontaine's instability concept remains one of the most widely cited frameworks for predicting redisplacement and defines a fracture as unstable when at least three of the following five factors are present: dorsal angulation greater than 20°, dorsal comminution, intra-articular extension, an associated ulnar fracture, and age over 60 years.[11] However, the predictive performance of these criteria for secondary displacement has been reported to be limited.[12] This limitation highlights the need for additional patient-specific parameters that may improve prediction of loss of reduction.

Bone quality has been suggested to influence fracture stability during non-surgical treatment of DRFs, as reduced BMD may predispose the fracture to progressive collapse and loss of reduction.[10] Radiographic assessment using the second metacarpal cortical percentage (2MCP) has been shown to correlate with BMD measured by dual-energy X-ray absorptiometry, and values below 50% have been reported to be suggestive of osteoporosis.[13,14] Reduced second metacarpal cortical thickness and osteoporosis have also been associated with greater fracture instability and a higher risk of loss of reduction in non-surgically treated DRFs.[15]

In addition to bone quality, muscle mass may also influence fracture stability, as sarcopenia has been associated with impaired physical performance, increased risk of falls, and fragility fractures in older adults.[16] In patients with DRFs, osteoporosis and sarcopenia are both common and may represent early manifestations of musculoskeletal frailty. Reduced bone quality together with diminished muscle mass and strength may compromise fracture stability and make maintenance of reduction during non-surgical treatment more difficult. In clinical practice and research settings, muscle mass can be assessed using imaging techniques such as computed tomography (CT), in which skeletal muscle area or psoas muscle area measured at the level of the third lumbar vertebra (L3) is commonly used as a surrogate for total body muscle mass.[17] Psoas muscle index was selected in the present study, as it can be readily calculated from lumbar CT images and may provide a practical imaging-based indicator of low muscle mass. However, although bone density and sarcopenia have each been investigated in relation to DRFs, their association with loss of reduction, particularly when assessed using radiographic bone quality and CT-based muscle mass measures, remains insufficiently studied.[10,16,18] Furthermore, the combined evaluation of 2MCP and PMI may provide a more comprehensive assessment of patient-related musculoskeletal factors by integrating both bone quality and muscle mass.

In the present study, we hypothesized that lower 2MCP and lower PMI could be associated with an increased risk of loss of reduction after closed reduction and cast immobilization. We, therefore, aimed to determine whether 2MCP and psoas muscle index (PMI) were associated with loss of reduction in female patients with non-surgically treated DRFs and to examine these parameters in relation to conventional predictors of instability, including fracture pattern, lumbar CT-based bone density, and Lafontaine criteria.

PATIENTS AND METHODS

This single-center, retrospective study was conducted at Mersin University Faculty of Medicine, Department of Orthopedics and Traumatology between January 2014 and June 2025. Patients aged ≥ 18 years who were treated with closed reduction followed by cast immobilization and had standardized posteroanterior and lateral radiographs available at the time of diagnosis, immediately after reduction and casting, and at Week 4 during follow-up were included. Patients aged < 18 years who underwent surgical treatment at initial management or subsequently before completion of the four-week follow-up and had concomitant fractures other than distal ulna fractures were excluded. Those who were managed non-operatively despite meeting at least one radiographic criterion for surgical indication were also excluded, including post-reduction radial shortening greater than 3 mm, dorsal tilt greater than 10°, or intra-articular displacement or step-off greater than 2 mm.[19] In addition, those with incomplete medical records or missing or inadequate radiographic follow-up were excluded. Among the remaining patients, those without lumbar CT bone densitometry performed within three months of the injury date were further excluded. Of a total of 2,147 adult patients diagnosed with DRF, 92 who met the inclusion criteria were recruited. Since only

one patient was male, he was excluded due to the marked sex imbalance, resulting in a final cohort of 91 female patients. The study flowchart is shown in Figure 1. A written informed consent was obtained from each patient. The study protocol was approved by the Mersin University Health Sciences Research Ethics Committee (Date: 01.04.2026, No.: 2026/199). The study was conducted in accordance with the principles of the Declaration of Helsinki.

Demographic, clinical, and radiographic characteristics of the patients including age, height, AO/OTA fracture classification,[20] and lumbar CT densitometry T-scores were retrieved from the hospital database. Lumbar CT densitometry examinations were performed as part of clinical osteoporosis assessment, and no additional CT imaging was obtained for research purposes. Osteoporosis was defined as a CT densitometry T-score of ≤ −2.5.

Radiographic measurements

Posteroanterior and lateral wrist radiographs obtained at the time of injury, immediately after reduction, and at Week 4 following trauma were evaluated. Radiographs were considered standard when both views were available with adequate positioning and image quality for measurement.[21] Radiographic assessments were performed independently by two observers, both specialists in orthopedics and traumatology with one and four years of experience, respectively.

Each observer repeated all measurements after a one-week interval. For quantitative variables, the mean of the two measurements was calculated for each observer, and the final value was defined as the average of the two observers' mean values. When substantial discrepancies were noted between measurements, the images were re-evaluated in consultation with a fellowship-trained hand surgeon. For categorical variables, if the two assessments were concordant, the result was accepted as the observer's final decision. If they were discordant, the images were re-evaluated in consultation with a fellowship-trained hand surgeon, and a consensus decision was reached.

Volar tilt, radial inclination, radial height, ulnar variance, and intra-articular displacement were

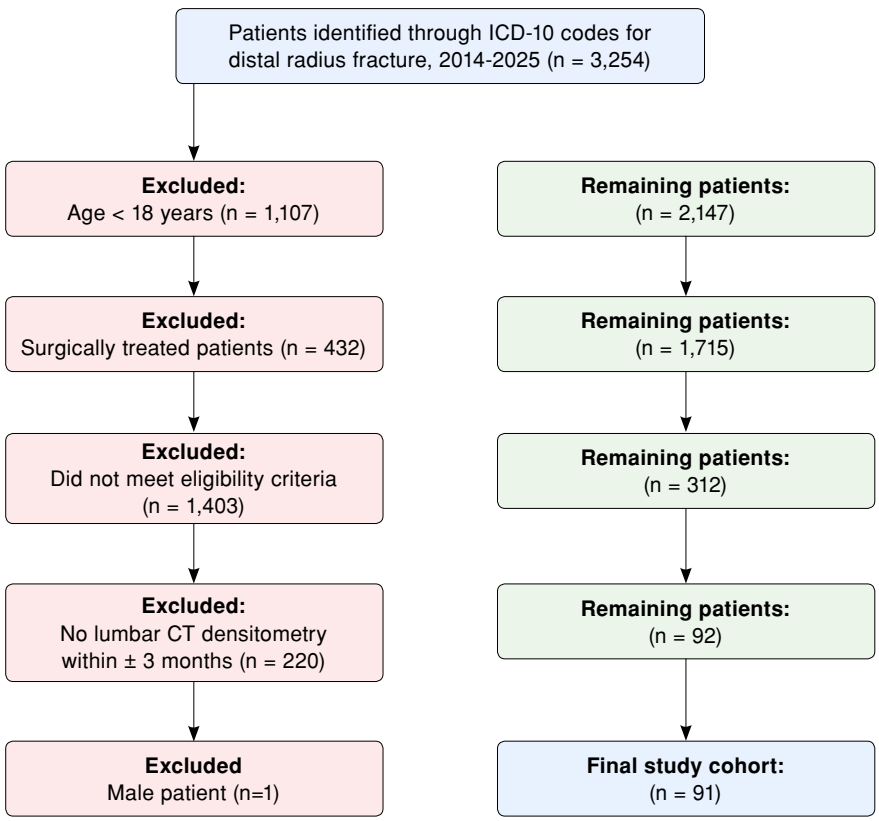

FIGURE 1. Study flowchart.
CT, computed tomography.

measured on each radiograph using previously described techniques[12,22] with digital imaging software. Lafontaine instability criteria[11] were assessed on the pre-reduction radiographs. Fractures were classified as unstable when at least three of the following five factors were present: dorsal angulation greater than 20°, dorsal comminution, intra-articular extension, an associated ulnar fracture, and age over 60 years.

The 2MCP was measured on the initial injury radiographs using a true posteroanterior hand or wrist view, according to the method described by Schreiber et al.[13] The measurement was obtained at the mid-diaphyseal level of the second metacarpal, and 2MCP was calculated as the cortical thickness ratio. Based on previously reported criteria, values below 50% were considered consistent with osteoporosis (Figure 2).

The cross-sectional area of the bilateral psoas muscles was measured on axial CT images at the level of the L3, obtained from the lumbar CT densitometry examinations. The measurements were performed on axial CT images reconstructed according to the institutional lumbar CT densitometry protocol. For each patient, a single axial image at the mid-vertebral level of L3 was selected as the reference slice for psoas muscle measurement. The right and left psoas muscle borders were manually outlined on this slice, and the total bilateral psoas muscle area was calculated. The PMI was, then, calculated according to the method described by Jones et al.,[23] as the total bilateral psoas muscle area divided by the square of the patient's height in meters (m^2) (Figure 3). The same standardized slice-selection and measurement approach was used by both observers.

Definition of loss of reduction

Loss of reduction was defined as the presence of any of the following on follow-up radiographs: radial shortening greater than 3 mm, dorsal tilt greater than 10°, or intra-articular displacement or step-off greater than 2 mm.[19]

Statistical analysis

Statistical analysis was performed using the IBM SPSS version 26.0 software (IBM Corp., Armonk, NY, USA). Continuous variables were presented in mean ± standard deviation (SD) or median (min-max), while categorical variables were presented in number and frequency. Normality was assessed using the Kolmogorov-Smirnov test. Between-group comparisons were performed using the independent samples t-test or Welch's t-test,

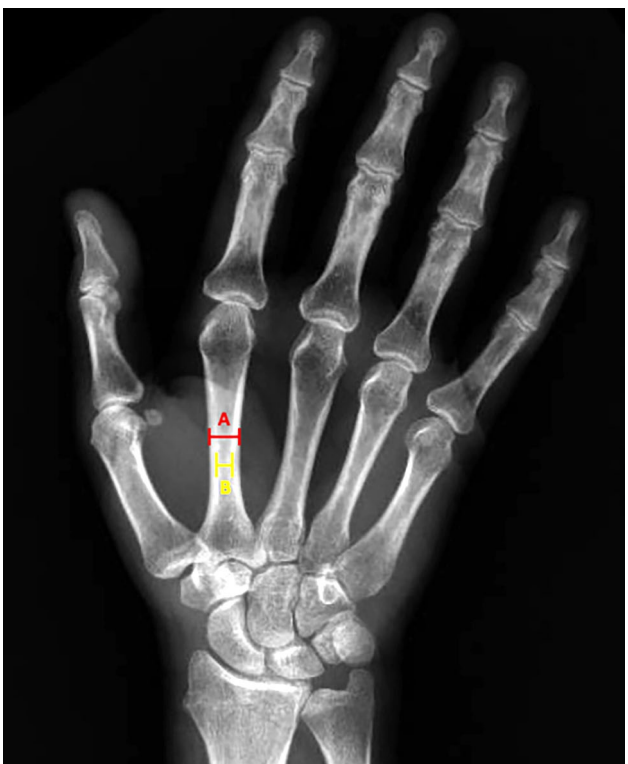

FIGURE 2. Measurement of the second metacarpal cortical percentage (2MCP) on a posteroanterior radiograph. The measurement was performed at the mid-diaphyseal level of the second metacarpal and calculated as [(A-B) / A] × 100, where A represents the outer cortical diameter and B represents the medullary diameter.

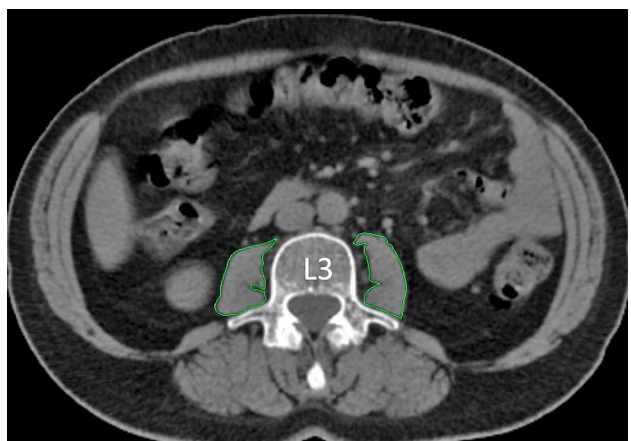

FIGURE 3. Measurement of the PMI on axial computed tomography at the level of the third lumbar vertebra (L3). The right and left psoas muscle borders were manually outlined on the selected axial slice, and the total bilateral psoas muscle area was divided by height squared to calculate PMI.
PMI, psoas muscle index.

when appropriate, and the Mann-Whitney U test for continuous variables, and the chi-square or Fisher exact test for categorical variables. Diagnostic performance was evaluated using sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) based on predefined cut-off values: age ≥ 65 years, Lafontaine instability ≥ 3 criteria,[11] CT densitometry T-score ≤ –2.5,[10] 2MCP < 50%,[13] and PMI ≤ 3.6.[17] A multivariate binary logistic regression model including age ≥ 65 years, AO/OTA Type C fracture pattern, 2MCP-defined osteoporosis, and low PMI was used to estimate adjusted odds ratios (ORs) with 95% confidence intervals (CIs). Receiver operating characteristic (ROC) curve analysis was performed for continuous 2MCP and PMI values, and areas under the curve (AUCs) were reported with 95% CIs. Agreement between CT densitometry-defined osteoporosis and 2MCP-defined osteoporosis was assessed using Cohen's kappa coefficient. Interobserver reliability was evaluated using a two-way random-effects, absolute-agreement, single-measure intraclass correlation coefficient (ICC) model. A p value of < 0.05 was considered statistically significant.

RESULTS

All patients included in the study were female with a mean age of 63.0 ± 8.2 (range, 44 to 84) years. According to the AO/OTA classification, A2 fractures were observed in 39 (42.9%) patients, A3 in 19 (20.9%), B1 in seven (7.7%), B2 in 11 (12.1%), B3 in three (3.3%), C1 in five (5.5%), C2 in six (6.6%), and C3 in one (1.1%) patient. According to the Lafontaine criteria, 41 (45.1%) fractures were classified as unstable and 50 (54.9%) as stable.

The mean lumbar CT bone densitometry T-score was –2.56 ± 0.73 (range, –4.25 to –0.91). Computed tomography densitometry-defined osteoporosis was present in 36 (39.6%) patients. The mean 2MCP was 52.3% ± 8.0% (range, 33% to 71%), and 32 (35.2%) patients had 2MCP-defined osteoporosis. The mean PMI was 4.07 ± 0.66 (range, 2.21 to 5.55) (Table I).

Loss of reduction occurred in 23 (25.3%) patients, whereas reduction was maintained in 68 (74.7%) patients. Patients with and without loss of reduction did not differ significantly in the mean age (61.2 ± 8.2 *vs.* 63.6 ± 8.2 years; p = 0.233). However,

TABLE I
Baseline patient, fracture, and imaging characteristics of the study cohort

Variables	n	%	Mean ± SD	Range
Age (year)			63.0 ± 8.2	44-84
AO/OTA classification				
A2	39	42.9		
A3	19	20.9		
B1	7	7.7		
B2	11	12.1		
B3	3	3.3		
C1	5	5.5		
C2	6	6.6		
C3	1	1.1		
Lafontaine classification				
Stable	50	54.9		
Unstable	41	45.1		
CT bone densitometry T-score			–2.56 ± 0.73	–4.25 to –0.91
CT densitometry-defined osteoporosis				
No	55	60.4		
Yes	36	39.6		
Second metacarpal cortical percentage			52.3 ± 8.0	33-71
2MCP-defined osteoporosis				
No (≥ 50%)	59	64.8		
Yes (< 50%)	32	35.2		
Psoas muscle index			4.07 ± 0.66	2.21-5.55

SD, standard deviation; AO/OTA, Arbeitsgemeinschaft für Osteosynthesefragen/Orthopaedic Trauma Association; CT, computed tomography.

TABLE II
Comparison of patients with and without loss of reduction

Variables	Loss of reduction (n = 23)			Maintained reduction (n = 68)			*p*
	n	%	Mean ± SD	n	%	Mean ± SD	
Age (year)			61.2 ± 8.2			63.6 ± 8.2	0.233
AO/OTA classification							0.017
Type A	11	47.8		47	69.1		
Type B	5	21.7		16	23.5		
Type C	7	30.4		5	7.4		
Lafontaine criteria count			3.17 ± 1.11			1.87 ± 1.20	< 0.001
Lafontaine instability	18	78.3		23	33.8		< 0.001
CT bone densitometry T-score			–2.91 ± 0.65			–2.44 ± 0.72	0.006
CT densitometry-defined osteoporosis	16	69.6		20	29.4		0.001
2MCP (%)			47.2 ± 8.5			54.0 ± 7.2	0.001
2MCP-defined osteoporosis	17	73.9		15	22.1		< 0.001
Psoas muscle index			3.40 ± 0.58			4.29 ± 0.52	< 0.001
Low psoas muscle index	18	78.3		6	8.8		< 0.001

SD, standard deviation; AO/OTA, Arbeitsgemeinschaft für Osteosynthesefragen/Orthopaedic Trauma Association; CT, computed tomography; 2MCP, second metacarpal cortical percentage.

the distribution of AO/OTA fracture types differed significantly between groups ($p = 0.017$), with Type C fractures being more frequent in patients with loss of reduction.

The Lafontaine criteria count was higher in patients with loss of reduction than in those with maintained reduction (3.17 ± 1.11 *vs.* 1.87 ± 1.20; $p < 0.001$). Lafontaine instability was also more frequent in the loss-of-reduction group (78.3% *vs.* 33.8%; $p < 0.001$). Patients with loss of reduction had lower CT bone densitometry T-scores (–2.91 ± 0.65 *vs.* –2.44 ± 0.72; $p = 0.006$), lower 2MCP values (47.2% ± 8.5% *vs.* 54.0% ± 7.2%; $p = 0.001$), and lower PMI values (3.40 ± 0.58 *vs.* 4.29 ± 0.52; $p < 0.001$). Computed tomography densitometry-defined osteoporosis, 2MCP-defined osteoporosis, and low PMI were significantly more common in patients with loss of reduction (Table II).

In the multivariate logistic regression model using predefined cut-off values, 2MCP-defined osteoporosis remained independently associated with loss of reduction (adjusted OR = 7.22; 95% CI: 1.16-45.06; $p = 0.034$). Low PMI also remained independently associated with loss of reduction (adjusted OR = 25.52; 95% CI: 5.33-122.14; $p < 0.001$). Age ≥ 65 years and AO/OTA Type C fracture pattern were not independently associated with loss of reduction in this model (Table III).

Using predefined thresholds or definitions, low PMI shared the highest sensitivity with Lafontaine instability and showed the highest PPV and NPV for predicting loss of reduction, with sensitivity, specificity, PPV, and NPV values of 78.3%, 91.2%, 75.0%, and 92.5%, respectively. The corresponding values were 73.9%, 77.9%, 53.1%, and 89.8% for 2MCP-defined osteoporosis; 69.6%, 70.6%, 44.4%, and

TABLE III
Multivariable logistic regression analysis using predefined cutoff values for loss of reduction

Predictor	Cutoff / definition	Adjusted OR	95% CI	*p*
Age	≥ 65 years	0.18	0.03-1.21	0.078
AO/OTA Type C fracture	Type C	5.39	0.77-37.93	0.090
2MCP-defined osteoporosis	2MCP < 50%	7.22	1.16-45.06	0.034
Low PMI	PMI ≤ 3.6	25.52	5.33-122.14	< 0.001

OR, odds ratio; CI, confidence interval; AO/OTA, Arbeitsgemeinschaft für Osteosynthesefragen/Orthopaedic Trauma Association; 2MCP, second metacarpal cortical percentage; PMI, psoas muscle index.

TABLE IV
Diagnostic performance of predefined cut-off values for predicting loss of reduction

Predictor	Cutoff / definition	Sensitivity (%)	Specificity (%)	PPV (%)	NPV (%)
Age	≥ 65 years	30.4	52.9	17.9	69.2
AO/OTA Type C fracture	Type C	30.4	92.6	58.3	79.7
Lafontaine instability	≥ 3 criteria	78.3	66.2	43.9	90.0
CT densitometry-defined osteoporosis	T-score ≤ –2.5	69.6	70.6	44.4	87.3
2MCP-defined osteoporosis	2MCP < 50%	73.9	77.9	53.1	89.8
Low PMI	PMI ≤ 3.6	78.3	91.2	75.0	92.5

PPV, positive predictive value; NPV, negative predictive value; AO/OTA, Arbeitsgemeinschaft für Osteosynthesefragen/Orthopaedic Trauma Association; CT, computed tomography; 2MCP, second metacarpal cortical percentage; PMI, psoas muscle index.

87.3% for CT densitometry-defined osteoporosis; and 78.3%, 66.2%, 43.9%, and 90.0% for Lafontaine instability (Table IV).

The ROC curve analysis showed that the AUC was 0.738 (95% CI: 0.604-0.854) for 2MCP and 0.846 (95% CI: 0.734-0.942) for PMI. The ROC-derived cut-off values were 48% for 2MCP and 3.65 for PMI (Figures 4 and 5). Agreement between CT densitometry-defined osteoporosis and 2MCP-defined osteoporosis was excellent, with a Cohen's kappa coefficient of 0.859.

Interobserver reliability was excellent for evaluated radiographic and CT-based measurements, with ICC values ranging from 0.904 to 0.996. The ICC values for the key study measurements were 0.987 for 2MCP and 0.994 for psoas muscle area (Table V).

DISCUSSION

In the present study, we investigated whether 2MCP and PMI were associated with loss of reduction in female patients with non-surgically treated DRFs. In our cohort, approximately one-quarter of non-surgically treated DRFs developed loss of reduction during follow-up. In group comparisons, AO/OTA Type C fracture pattern, Lafontaine instability, CT densitometry-defined osteoporosis, 2MCP-defined osteoporosis, and low PMI were more frequent among patients with loss of reduction, while age did not significantly differ between the groups. In the multivariate model adjusted for age ≥ 65 years, AO/OTA Type C fracture pattern, 2MCP-defined osteoporosis, and low PMI, both 2MCP-defined osteoporosis and low PMI remained independently associated with loss of reduction.

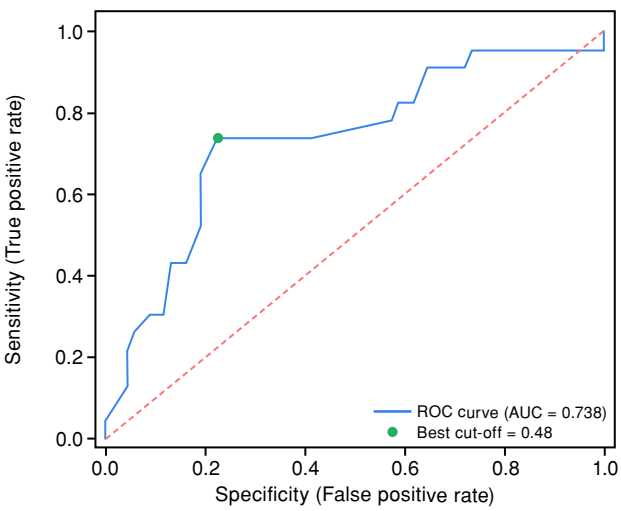

FIGURE 4. Receiver operating characteristic (ROC) curve of second metacarpal cortical percentage (2MCP) for predicting loss of reduction. The area under the curve was 0.738 (95% CI: 0.604-0.854), and the ROC-derived cut-off value was 48%.

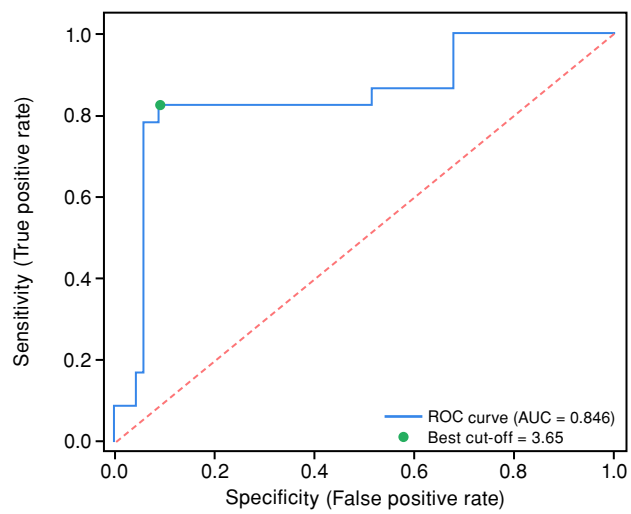

FIGURE 5. Receiver operating characteristic (ROC) curve of psoas muscle index (PMI) for predicting loss of reduction. The area under the curve was 0.846 (95% CI: 0.734-0.942), and the ROC-derived cut-off value was 3.65.

TABLE V
Interobserver reliability of radiographic and computed tomography-based measurements

Measurement	Mean difference (O1-O2)	Mean absolute difference	ICC	95% CI
2MCP (%)	0.06	0.96	0.987	0.981-0.992
Psoas muscle area	0.00	0.16	0.994	0.991-0.996
Post-reduction volar tilt (°)	0.08	0.56	0.989	0.983-0.992
Post-reduction ulnar variance (mm)	0.03	0.14	0.936	0.904-0.957
Post-reduction intra-articular step-off (mm)	0.01	0.01	0.928	0.893-0.952
Fourth-week volar tilt (°)	–0.01	0.38	0.996	0.994-0.997
Fourth-week ulnar variance (mm)	0.02	0.18	0.961	0.942-0.974
Fourth-week intra-articular step-off (mm)	0.03	0.12	0.904	0.858-0.935

O1, observer 1; O2, observer 2; ICC, intraclass correlation coefficient; CI, confidence interval; 2MCP, second metacarpal cortical percentage. ICC values were interpreted as follows: < 0.50, poor reliability; 0.50-0.75, moderate reliability; 0.75-0.90, good reliability; and > 0.90, excellent reliability.

These findings suggest that simple imaging-based measures of bone and muscle status, particularly 2MCP and PMI, may serve as practical and readily available imaging biomarkers for identifying patients at increased risk of secondary displacement following conservative treatment of DRFs.

Loss of reduction still remains a major challenge in the non-surgical management of DRFs. Previous studies have shown that redisplacement after an initially acceptable reduction is common, with reported rates varying considerably across series. In some contemporary studies, this rate has been reported to reach as high as around 60%, highlighting that redisplacement remains a frequent and clinically relevant problem after conservative treatment.[3,12,22,24,25] It has been emphasized that redisplacement may still occur in a substantial proportion of adequately reduced DRFs during cast immobilization, and that preventing this complication is a major treatment goal due to its potential consequences, including malunion and secondary surgery.[26,27] Consistent with this clinical concern, loss of reduction was observed in 25.3% of patients in our cohort, which had a mean age of 63.0 years. In this context, the ability to identify patients at increased risk of loss of reduction is clinically important, as it may improve initial treatment selection, guide closer radiographic follow-up, and help avoid late failure of conservative management.

The higher frequency of AO/OTA Type C fractures among patients with loss of reduction is clinically plausible, as more advanced fracture patterns have been associated with a greater risk of redisplacement. In particular, Zhao et al.[24] identified both age and AO/OTA type as significant factors associated with redisplacement after non-surgical treatment. Type C fractures, by definition, represent more complex complete articular injuries with greater comminution and less intrinsic stability than less severe fracture patterns.[20] In the present study, Type C fractures were more frequent among patients with loss of reduction; however, this association did not remain significant in the multivariate model. Similarly, although advancing age has been reported as a risk factor for redisplacement in previous studies,[24-26] age was not significantly associated with loss of reduction in our cohort.

Although the Lafontaine criteria remain one of the most widely cited and historically important frameworks for assessing DRF instability,[11] their predictive performance has been reported to be variable.[11,12] In the present study, Lafontaine instability was more frequent among patients with loss of reduction and showed relatively high sensitivity and NPV. However, its specificity and PPV were relatively limited, supporting the need for additional patient-related musculoskeletal parameters in risk assessment. Ulmer et al.[15] reported that, within the original Lafontaine model, only initial fracture displacement was associated with four-week sagittal plane displacement, whereas age, dorsal comminution, intra-articular extension, and associated ulnar fracture were not. More recently, Dissaneewate et al.[28] externally validated the Lafontaine criteria and concluded that their discriminative performance for predicting unstable DRFs was unacceptable. Taken together, these findings suggest that conventional radiographic instability criteria remain clinically relevant but may be insufficient when used alone, as maintenance of

reduction can be also affected by bone quality and other patient-specific biological factors that cannot be fully explained by radiographic features alone.

Computed tomography densitometry-defined osteoporosis was more frequent among patients with loss of reduction in our cohort. This finding indicates that systemic skeletal fragility may influence the maintenance of reduction after non-surgical treatment. However, previous studies have reported conflicting results regarding the relationship between BMD and DRF stability. Cho et al.[29] found no significant difference in lumbar BMD between patients with and without loss of reduction, and concluded that reduction loss was more strongly related to initial dorsal comminution and ulnar variance than to BMD itself. Likewise, Robin et al.[30] reported that BMD of the spine and femoral neck was not significantly related to DRF stability in patients over 65 years of age. It should also be noted that lumbar CT-derived T-scores are not directly interchangeable with dual-energy X-ray absorptiometry (DXA)-derived measurements, as DXA remains the reference standard for osteoporosis assessment and CT-based values may be influenced by acquisition and reconstruction protocols.[31] Taken together, these findings suggest that although systemic bone density measurements may reflect overall skeletal fragility, they may not fully capture the local mechanical conditions that determine whether fracture reduction can be maintained during follow-up.

Although 2MCP has gained attention only in recent years and has not yet become part of routine daily practice, it appears to be a simple, inexpensive, and promising tool for opportunistic assessment of bone quality.[32] Beyond its role as a surrogate marker of bone quality, more recent studies have also supported the prognostic value of 2MCP in DRFs treated non-surgically. Ghodasra et al.[10] showed that low 2MCP was associated with greater loss of reduction, particularly when combined with instability features, whereas Ulmer et al.[15] found that 2MCP and initial fracture displacement outperformed the original Lafontaine model in predicting fracture displacement at follow-up. More recently, Jecan et al.[33] also supported the value of second metacarpal cortical measurements in predicting secondary displacement after conservative treatment. In our cohort, 2MCP-defined osteoporosis remained independently associated with loss of reduction after adjustment for age ≥ 65 years, AO/OTA Type C fracture pattern, and low PMI. The ROC analysis identified an exploratory cut-off value of 48%, supporting the potential role of 2MCP as a practical imaging-based marker of bone quality. These findings support the view that 2MCP is not only a practical indicator of bone quality, but also a clinically relevant parameter for identifying patients at increased risk of secondary displacement after non-surgical treatment.

While direct evidence linking PMI specifically to secondary displacement in DRFs remains limited, previous studies have shown that sarcopenia and low skeletal muscle mass are clinically relevant in this setting.[34-36] In this context, PMI, measured at the L3 level on CT, has been proposed as a practical surrogate marker of low muscle mass, and cut-off values around 3.6 have been suggested for identifying reduced muscle mass in clinical studies.[17,23] In our cohort, low PMI remained independently associated with loss of reduction after adjustment for age ≥ 65 years, AO/OTA Type C fracture pattern, and 2MCP-defined osteoporosis. The ROC analysis identified an exploratory cut-off value of 3.65, which was very close to the predefined threshold, supporting the potential role of PMI in risk stratification. As PMI can be derived relatively easily from routine CT images, it may help identify patients at increased risk of secondary displacement after non-surgical treatment. However, PMI should be interpreted as a surrogate marker of low muscle mass rather than a diagnostic marker of sarcopenia.

Nonetheless, this study has several limitations that should be acknowledged. First, its single-center, retrospective design may have introduced selection bias and limits the generalizability of the findings. In particular, the requirement for lumbar CT densitometry within three months of injury resulted in a highly selected cohort and may limit the applicability of the results to the broader DRF population. Second, the cohort was relatively small and consisted only of female patients. This was mainly because, among the patients who met the imaging eligibility criteria, nearly all were women; only one male patient remained after application of the study selection criteria and was, therefore, excluded owing to the marked sex imbalance. Accordingly, the findings may not be directly applicable to male patients. Third, loss of reduction was assessed at the fourth week after injury, and patients who underwent surgery before this time point were excluded; therefore, late redisplacement or early failure requiring operative treatment may not have been fully captured. Fourth, bone density was evaluated using lumbar CT-based densitometry rather than dual-energy X-ray absorptiometry,

which is usually accepted as the reference standard for osteoporosis assessment. Nevertheless, CT-based evaluation was used, since these images also allowed calculation of the PMI, thereby enabling simultaneous assessment of bone density and muscle mass from the same imaging dataset. Fifth, although both 2MCP and PMI are practical and readily obtainable surrogate measures, they do not provide a comprehensive assessment of bone quality or sarcopenia, which are multidimensional conditions. Finally, the number of outcome events was limited, and the ROC-derived cut-off values were obtained from the same cohort; therefore, these findings and thresholds should be considered exploratory until externally validated.

In conclusion, our study results showed that 2MCP-defined osteoporosis and low PMI were independently associated with loss of reduction after non-surgical treatment of DRFs in female patients. These findings suggest that practical imaging-based parameters reflecting bone quality and muscle mass may provide additional value in identifying patients at increased risk of secondary displacement. Given the retrospective design, selected cohort, and limited number of outcome events, these results should be considered exploratory and hypothesis-generating rather than definitive evidence of predictive utility, and require validation in larger prospective studies before being incorporated into routine treatment decision-making.

Data Sharing Statement: The data that support the findings of this study are available from the corresponding author upon reasonable request.

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