Association of Modifiable Risk Factors with Bone Mineral Density among People with Distal Radius Fracture: A Cross-Sectional Study

Neha Dewan, PhD, MPT;^{*†} Joy C. MacDermid, PhD, PT;^{*†‡} Ruby Grewal, MD, FRCSC;^{†‡}
Karen Beattie, PhD, BSc^{*§}

ABSTRACT

Purpose: This study determined the extent to which modifiable risk factors (balance, muscle strength, and physical activity [PA]) explained variability in bone mineral density (BMD) among people with a recent distal radius fracture (DRF). **Method:** This cross-sectional study included 190 patients, aged 50–80 years, with a DRF. Participants were assessed for balance, muscle strength, PA, fracture-specific pain, and disability. Areal BMD at the femoral neck (BMD-FN) and total hip (BMD-TH) was assessed. Correlation and multiple linear regression was used to determine the contribution of modifiable risk factors to BMD. **Results:** Balance, handgrip strength, knee extension strength, and plantar-flexion strength had significant bivariate associations with BMD-FN. There was a weak to moderate correlation ($r = 0.25$ – 0.40 ; $p < 0.05$) of balance and grip strength with BMD. Grip strength independently ($p < 0.05$) explained 17% and 12% of the variability in BMD-FN ($n = 81$) and BMD-TH ($n = 82$), respectively. Stratified by age, balance ($R^2 = 0.10$; $p = 0.04$) and grip strength ($R^2 = 0.32$; $p = 0.003$) were independent significant predictors of BMD-FN among women aged 50–64 years and 65–80 years, respectively. **Conclusions:** Grip strength of the unaffected hand is independently associated with BMD-FN and BMD-TH in people with recent DRF. It may act as a surrogate for general bone health, frailty, or overall muscle strength rather than as a direct target for intervention.

Key Words: bone density; distal radius fracture; muscle strength; osteoporosis; risk factors.

RÉSUMÉ

Objectif : déterminer dans quelle mesure les facteurs de risque modifiables (équilibre, force musculaire et activité physique [AP]) expliquait la variabilité de l'ostéodensitométrie, ou densité minérale osseuse (DMO), chez les personnes victimes d'une récente fracture du radius distal (FRD). **Méthodologie :** la présente étude transversale incluait 190 patients de 50 à 80 ans victimes d'une FRD. Les chercheurs ont évalué l'équilibre, la force musculaire, l'AP, la douleur propre à la fracture et l'incapacité des participants. Ils ont évalué la DMO surfacique du col du fémur (DMO-CF) et de la hanche totale (DMO-HT). Ils ont utilisé la corrélation et la régression linéaire multiple pour déterminer l'apport des facteurs de risque modifiables à la DMO. **Résultats :** l'équilibre, la force de préhension de la main, la force d'extension du genou et la force de flexion plantaire avaient des associations bivariées significatives avec la DMO-CF. On constatait une corrélation faible à modérée ($r = 0,25$ à $0,40$; $p < 0,05$) de l'équilibre et de la force de préhension avec la DMO. La force de préhension seule ($p < 0,05$) expliquait 17 % de la variabilité de la DMO-CF ($n = 81$) et 12 % de la DMO-HT ($n = 82$). Stratifiées en fonction de l'âge, l'équilibre ($R^2 = 0,10$; $p = 0,04$) et la force de préhension ($R^2 = 0,32$; $p = 0,003$) étaient des prédicteurs indépendants importants de DMO-CF chez les femmes de 50 à 64 ans et de 65 à 80 ans, respectivement. **Conclusion :** la force de préhension de la main non atteinte s'associe de manière indépendante à la DMO-CF et à la DMO-HT chez les personnes victimes d'une récente FRD. Elle peut remplacer l'évaluation de la santé osseuse générale, de la fragilité ou de la santé musculaire globale plutôt que d'être une cible directe d'intervention.

Osteoporosis, defined as a reduction in bone mineral density (BMD) and increased bone resorption, is a public

health concern because it results in 8.9 million fractures per year around the world.¹ Both the incidence and the

From the: ^{*}School of Rehabilitation Science, Faculty of Health Sciences; [§]Department of Medicine, McMaster University, Hamilton; [†]Roth I McFarlane Clinical Research Laboratory, Hand and Upper Limb Centre, St. Joseph's Health Care; [‡]Department of Surgery, Schulich School of Medicine & Dentistry, Western University, London, Ont.

Correspondence to: Neha Dewan, Hand and Upper Limb Clinical Research Lab, St. Joseph's Health Care, DB-222, 268 Grosvenor St., London, ON N6A 4V2; nehadewan1@yahoo.com.

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prevalence of osteoporosis are expected to increase with the rapidly increasing size of the aging population. This creates a crucial need to identify people at risk of low BMD and bone fragility leading to osteoporotic (OP) fractures.

Distal radius fracture (DRF) is a well-documented, early sentinel event for secondary OP fractures.² Cohort data suggest that a DRF is associated with a 5 times increased risk of vertebral fractures in women, a 10 times increased risk of vertebral fracture in men,³ and a 2 times increased risk of hip fracture in women aged 70 years or older.⁴ Given the substantial burden of OP fractures secondary to DRF, it is extremely important to investigate the modifiable risk factors associated with bone fragility in this population.⁵ Studies have reported that persons aged 50 years or older with DRF seem to have a preferential bone loss at the distal forearm and generalized low bone mass, indicating poor bone health.⁶ A study by Ingle and colleagues demonstrated a significant decrease in BMD at 6 weeks after fracture, with a mean loss of 9% ($p < 0.001$); this remained decreased at 1 year.⁶

BMD is often reported to be low among seniors and women with DRF.^{2,7} Indeed, well-known, non-modifiable risk factors, such as age and gender, are important to consider in stratifying people who may be at high risk of low BMD and future OP fractures such as DRF. Modifiable risk factors for low BMD and fractures include poor postural balance, decreased muscle strength, and low levels of physical activity (PA).^{8–10} Research has suggested that various physical therapy interventions can improve these risk factors, potentially leading to increased BMD and reduced risk of fracture, likely because of the reduced risk of falls.^{8–10}

Unlike patients with spine or hip fractures, relatively healthy people with DRF have been noted to neglect being screened for bone health.^{11,12} Also, it is not uncommon for therapists working in a busy fracture clinic to miss the opportunity to refer patients with DRF for BMD testing.^{13,14} Recently, studies have reported a physically inactive lifestyle,^{8,14–16} muscle and bone weakness,¹⁷ and postural imbalance^{16,18,19} among patients with DRF. A 2010 review on the use of hand therapy (rehabilitation provided by certified physical therapists and occupational therapists to patients with any conditions and disorders of the upper limb) in the management of DRF suggested that therapists have unique training, skills, and opportunities to screen for, and intervene in, modifiable risk factors such as postural balance, PA, muscle strength, and fracture-specific pain and disability among patients with DRF with significant bone fragility.⁸

However, over the course of specialization, physical therapists and hand therapists (physical therapists and occupational therapists with a specialization in hand therapy) may not continue to use these skills to identify patients at risk of secondary OP fractures.^{8–10} This might

be because of a lack of evidence on the extent to which modifiable risk factors (which can be modified with physical therapy) are associated with BMD in persons with recent DRF. Also, it is unknown whether there are any age- or gender-based differences in the association between modifiable risk factors and BMD in persons with recent DRF. It is important to improve the understanding of the modifiable risk factors that can explain variability in BMD in patients with DRF because this understanding can assist therapists to early identify, treat, and refer those who might be at risk of secondary OP fractures after DRF.

Thus, the purposes of this study were to determine the following in persons with recent DRF: (1) whether BMD and modifiable risk factors such as postural balance, PA, muscle strength, and fracture-specific pain and disability vary by age and gender; (2) the extent to which modifiable risk factors alone or in combination are associated with BMD and whether the strength of the association is modified after controlling for non-modifiable risk factors such as age and gender; and (3) which independent, modifiable risk factors are associated with BMD in an age-stratified sample of women with DRF.

METHODS

Overview of the study

This study was a cross-sectional analysis of data collected at 1–2 weeks post-DRF as part of a larger cohort study (consisting of 190 participants).

Study participants

Participants with a DRF who were aged 50–80 years were recruited from a single tertiary hospital in London, Ontario, between January 2010 and December 2013. All participants provided written, informed consent, and the study was approved by the Research Ethics Board of Western University. Excluded individuals were those with multiple fractures, a previously known history of hip or vertebral fracture, or neurological or cognitive impairments limiting their ability to provide informed consent.

Procedures

All participants were assessed for BMD, and they reported their fracture-specific pain and disability and PA on self-reported questionnaires during their baseline visit (i.e., 1–2 weeks after DRF). At the same time, a research assistant administered the standardized procedures for assessing postural balance and lower extremity (LE) muscle strength. Handgrip strength was assessed 3 months after DRF for both the affected and the unaffected hand. To confirm that the assessment procedures had been standardized, the research team reviewed all procedures at study onset.

Study variables

Outcome measures (dependent variables)

Assessing BMD using dual-energy X-ray absorptiometry (DXA) is the current gold standard for individuals at risk for OP fractures.^{20,21} Following the recommendation for BMD reporting in Canada, two sites were selected to assess BMD.^{22,23} Areal BMD at the femoral neck (BMD-FN) and total hip (BMD-TH; g/cm²) were measured using calibrated DXA with a lunar densitometer (GE-Lunar Prodigy DXA from GE Healthcare, Madison, WI). BMD-FN and BMD-TH were selected because they are recommended as reference standards for predicting the risk of an OP fracture.^{24,25} Moreover, we expected that assessing BMD at two sites would support the diagnostic sensitivity of our analyses.^{20,21}

Independent variables

Patients were assessed for balance, muscle strength of knee extensors (KEs) and plantar flexors (PFs), grip strength of the unaffected hand, PA, and fracture-specific pain and disability using reliable and validated measures. Balance was assessed using the Biodex Balance System SD (BBS, Biodex Medical Systems Inc., Shirley, NY).^{26,27} Balance testing on the Biodex was conducted on level 12 (a stable platform) and level 6 (a moderately unstable platform).²⁷ We used a standardized procedure, following the manufacturer's instructions, to evaluate the postural stability indicated by the limit of stability scores.^{26,27} The details of the standardized procedure are described in the manual and the previous literature.^{26,27} The overall stability index provided by the Biodex balance system was used for the analysis. Higher scores indicated better performance.

LE isometric muscle strength was measured using the Biodex System 3 Pro dynamometer (Biodex Medical Systems Inc., Shirley, NY).²⁸ Each patient was tested for knee extension and ankle plantar-flexion strength in both legs using standardized procedures, described in the manual and literature.^{28,29} An average of peak torque on three maximal voluntary isometric contractions was recorded. To limit the number of independent variables and to minimize the risk of collinearity in the regression analysis, strength in only the right-sided muscle was considered for the analysis.

Handgrip strength was determined using a hand-held dynamometer, the NK Digits Grip device (NK Biotechnical Corp., Minneapolis, MN), using standardized methods recommended by the American Society of Hand Therapists in the previous literature.^{30,31} Peak force was measured in kilograms and was reported as an average of two trials. Only grip strength of the unaffected hand was considered for the analysis.

Fracture-specific pain and disability were assessed using the Patient-Rated Wrist Evaluation (PRWE), a standardized, 15-item questionnaire.^{32,33} The PRWE consists

of two subscales evaluating pain and disability, respectively, at the wrist and hand. The total score ranges from 0 to 100, with a higher score indicating more pain and functional disability.

PA was evaluated using the nine-item Rapid Assessment of Physical Activity (RAPA) questionnaire.³⁴ Each question was answered with a yes or no response, and a score of 6 or more suggests a good level of PA.

Statistical analyses

Statistical analyses were carried out using STATA/SE, version 12.0 (StataCorp LLC, College Station, TX). Statistical significance was set at $p < 0.05$.

Descriptive statistics and t-test

We summarized the quantitative variables using mean and standard deviation stratified by age and gender. Counts and percentages were used for categorical data. Normality testing of dependent variables was performed using the Shapiro-Wilk test. BMD-FN and BMD-TH were treated as continuous variables. We used independent Student *t*-tests to investigate age- and gender-based differences in modifiable risk factors (postural balance, muscle strength, PA, and fracture-specific pain and disability) and BMD.

Correlation and simple linear regression analysis

Bivariate correlations were used to look for the strength and direction of relationships between dependent variables (BMD-FN and BMD-TH) and independent variables (balance, PA, handgrip strength, and KE and PF muscle strength). Correlation coefficients of 0.00–0.19 were defined as very weak; 0.20–0.39, as weak; 0.40–0.69, as moderate; 0.70–0.89, as strong; and 0.90–1.00, as very strong.³⁵ A partial correlation coefficient (r_p) was used to report the relationship between BMD and an independent variable, while controlling for all other independent variables. Simple linear regression was then used to explore the strength of association between BMD and individual modifiable and non-modifiable risk factors.

Multiple regression analysis

For subsequent analyses, modifiable risk factors were simultaneously considered in a multiple linear regression model to determine the extent of variability explained in BMD, while adjusted and unadjusted for age and gender. Independent variables were tested for multicollinearity, and only significant bivariate variables were selected for multiple linear regression. If KE and PF strength had similar bivariate associations with BMD, we included only KE muscle strength in our model to (1) limit the number of independent variables, (2) reflect the use of KE muscle strength as a modifiable risk factor to predict BMD in previous literature,³⁶ and (3) support knowledge translation because we thought it might be easier to assess KE muscle strength in routine clinical practice.

Moreover, we followed our analysis with formal regression diagnostics, including tests for homogeneity (Breusch-Pagan/Cook-Weisberg test) and linearity of residuals (histogram, Shapiro-Wilk test, pnorm, qnorm plots) and ensured that there were no violations of the assumptions of multicollinearity, homogeneity, normality, and linearity.³⁷ Residual versus fitted plots, leverage plots, and Cook's distance were used to identify observations with high influence. In addition, the interaction of modifiable risk factors with age and gender was tested.

Stepwise multiple linear regression analyses were performed for the whole study sample as well as in the age-stratified sample of women. The p -value for predictors to enter (p_e) was 0.05 and the p -value to remove (p_r) was initially set at ≥ 0.06 . However, the p -value to remove was adjusted to 0.10 (less stringent) for BMD-TH for the age-stratified sample of women so that we could arrive at the

most robust model. These prediction models generated coefficients of determination (R^2) as a measure of the extent of variability in the outcome explained by the regression. To confirm the sensitivity of the model, forward and backward selection regression methods were also used to determine whether all methods resulted in the same set of variables.

Power analysis

We used the G*Power software programme to determine whether we were fully powered to detect a significant relationship or association for our bivariate correlation and multiple regression analyses.³⁸ This programme considers the sample size and number of predictors to correctly identify the existing relationships. A priori sample size could not be calculated for this study because it was conducted as part of a larger cohort, which was powered to address different sets of questions.

Table 1 Age-Based Descriptive Characteristics of Variables among People with Distal Radius Fracture ($n = 190$)

Variable	Age 50–64 y ($n = 121$)		Age 65–80 y ($n = 69$)		p -value
	n (%)	Mean (SD)	n (%)	Mean (SD)	
Men	17 (14)		10 (15)		
Women	104 (86)		59 (85)		
BMD-FN	79 (65)	0.870 (0.103)	51 (74)	0.821 (0.133)	0.019*
BMD-TH	80 (66)	0.906 (0.131)	51 (74)	0.879 (0.139)	0.27
Balance	103 (85)	2.1 (1.2)	55 (80)	2.3 (1.1)	0.33
Grip strength (unaffected hand)	83 (69)	26.7 (7.7)	45 (65)	23.4 (7.3)	0.020*
Plantar flexor muscle strength (right)	98 (81)	67.8 (37.5)	63 (91)	57.06 (33.2)	0.06
Knee extensor muscle strength (right)	100 (83)	90.6 (39.9)	63 (91)	74.9 (29.7)	0.008*
Physical activity	108 (89)	6.1 (2.5)	66 (96)	6.0 (2.8)	0.83
Fracture-specific pain and disability	108 (89)	70.5 (18.4)	64 (93)	67.03 (21.8)	0.26

*Significant at $p < 0.05$.

BMD-FN = bone mineral density at the femoral neck; BMD-TH = bone mineral density at the total hip.

Table 2 Gender-Based Descriptive Characteristics of Variables among People with Distal Radius Fracture ($n = 190$)

Variable	Men ($n = 27$)		Women ($n = 163$)		p -value
	n (%)	Mean (SD)	n (%)	Mean (SD)	
Age 50–64 y	17 (63)		104 (64)		
Age 65–80 y	10 (37)		59 (36)		
BMD-FN	20 (74)	0.949 (0.134)	111 (68)	0.833 (0.105)	<0.001*
BMD-TH	20 (74)	1.009 (0.142)	112 (69)	0.875 (0.122)	<0.001*
Balance	20 (74)	3.2 (0.9)	140 (86)	2.0 (1.1)	<0.001*
Grip strength (unaffected hand)	18 (67)	37.5 (9.9)	111 (68)	23.5 (5.2)	<0.001*
Plantar flexor muscle strength (right)	23 (85)	92.2 (40.6)	140 (86)	58.6 (33.1)	<0.001*
Knee extensor muscle strength (right)	24 (89)	123.6 (51.4)	141 (87)	78.0 (29.3)	<0.001*
Physical activity	26 (96)	5.9 (2.8)	150 (92)	6.1 (2.6)	0.76
Fracture-specific pain and disability	25 (93)	74.4 (12.6)	149 (91)	68.1 (21.0)	0.14

*Significant at $p < 0.001$.

BMD-FN = bone mineral density at the femoral neck; BMD-TH = bone mineral density at the total hip.

RESULTS

Participant characteristics

Our study sample consisted of 163 women and 27 men with DRF (with a mean age of 62.11 [SD 7.68] y). Approximately 93% of our sample was right-hand dominant; 40% had injured their dominant hand. The age- and gender-stratified descriptive statistics are presented as means and standard deviations in Tables 1 and 2. The majorities were in the 50–64-year age group and were predominantly women. Although we had more female participants, the proportion of men and women in the two age groups was similar. Individuals aged 65–80 years had a significantly ($p < 0.05$) lower BMD-FN, grip strength, and PF muscle strength than those aged 50–64 years (see Table 1). Although not statistically significant, BMD-TH, balance, PA, KE muscle strength, and fracture-specific pain and disability were comparatively lower among the small sample of patients aged 65–80 years with DRF (see Table 1). Women had a significantly ($p < 0.05$) lower BMD-FN, BMD-TH, balance, grip strength, and PF and KE muscle strength than men (see Table 2).

Correlation and simple linear regression

Relationship and association between BMD and individual predictors

BMD-FN showed a positive, weak to moderate, significant correlation ($r = 0.25$ – 0.40) with handgrip strength, PF strength, KE strength, and balance (see Table 3). BMD-TH presented a positive, weak, significant relationship with grip strength ($r = 0.35$; $p < 0.001$) and balance ($r = 0.28$; $p = 0.002$; see Table 3). On controlled correlation analysis, as represented by partial r (r_p), none of the modifiable risk factors were significantly related to BMD-FN or BMD-TH. Simple linear regression analyses revealed that balance, grip strength, PF strength, KE strength, and age were each significantly associated with BMD-FN. However, only balance and grip strength showed a significant ($p < 0.05$) association with BMD-TH (see Table 3).

Multiple regression

Variability in BMD as explained by modifiable risk factors

The normality assumptions were met ($p > 0.05$) for both dependent variables (BMD-FN and BMD-TH). Regression diagnostics determining the appropriateness of the data for multiple regression suggested the mild violation of the assumption of normality for residuals (BMD-FN $p = 0.04$; BMD-TH $p = 0.05$). One participant was identified as the influential observation, with Cook's distance greater than $4/n$, and was removed with no change in the overall fit of the model. In our final prediction model for BMD-FN and BMD-TH, there was no multicollinearity among independent variables, the homogeneity assumption was fulfilled ($p > 0.05$), and residuals were normally distributed ($p > 0.05$). When adjusted for the non-modifiable risk factors of age and gender, none of the modifiable risk factors independently explained the variability in BMD, but the modifiable risk factors collectively accounted for significant ($p < 0.05$) variability in BMD-FN ($R^2 = 20\%$) and BMD-TH ($R^2 = 17\%$). There was no significant interaction of age or gender with any of the modifiable risk factors.

We were not powered to test the interactions among modifiable risk factors; thus, these were not tested because this activity needed a large sample. When unadjusted for age or gender (see Table 4), grip strength of the unaffected hand explained a small but significant ($p < 0.05$) amount of the variability in BMD-FN and BMD-TH.

Stepwise multiple linear regression

Grip strength was the only independent variable explaining 17% and 12% of the total variability in BMD-FN ($F_{1,79} = 15.23$; $p < 0.001$) and BMD-TH ($F_{1,80} = 10.93$, $p = 0.001$), respectively, and all other modifiable and non-modifiable risk factors were removed from the model (see Table 5).

The age-stratified stepwise regression analysis, exploring the association between BMD and modifiable risk

Table 3 Bivariate Correlation and Univariate Association between Individual Modifiable Risk Factors and BMD-FN and BMD-TH

Variable	BMD-FN						BMD-TH					
	No.	r	B (p -value)	R^2	r_p ($n = 78$)		No.	r	B (p -value)	R^2	r_p ($n = 78$)	
Balance	116	0.25*	0.02 (0.007)*	0.06*	0.07		118	0.28*	0.03 (0.002)*	0.08*	0.11	
Grip strength (unaffected hand)	92	0.40†	0.006 (< 0.001)*	0.16†	0.10		92	0.35†	0.006 (0.001)†	0.12†	0.13	
PF muscle strength (right)	119	0.26*	0.0008 (0.005)*	0.07*	0.15		120	0.13	0.0005 (0.14)	0.02	0.06	
KE muscle strength (right)	120	0.27*	0.0009 (0.003)*	0.07*	−0.01		122	0.17	0.0006 (0.06)	0.03	−0.09	
Physical activity	122	−0.02	−0.003 (0.69)	0.001	0.02		122	−0.08	−0.008 (0.35)	0.007	−0.12	
Fracture-specific pain and disability	124	−0.02	−0.0001 (0.85)	0.0003	−0.03		124	0.04	0.0003 (0.62)	0.002	0.02	

* $p < 0.05$. † $p < 0.001$.

BMD-FN = bone mineral density at the femoral neck; BMD-TH = bone mineral density at the total hip; PF = plantar flexor; KE = knee extensor.

Table 4 Linear Regression Modeling of the Associations between Modifiable Risk Factors and Bone Mineral Density (Unadjusted for Age or Gender)

Variable	BMD-FN (<i>n</i> = 81)		BMD-TH (<i>n</i> = 82)	
	B (95% CI)*	β*	B (95% CI)*	β*
Model summary				
<i>R</i> ²	0.17 [†]	0.14 [†]		
Adjusted <i>R</i> ²	0.14	0.11		
SE	0.11	0.13		
Coefficients				
Constant	0.69 (0.60, 0.77)	—	0.72 (0.62, 0.82)	—
Balance	0.007 (−0.01, 0.03)	0.07	0.02 (−0.008, 0.04)	0.14
Grip strength	0.005 (0.0008, 0.009) [†]	0.34	0.006 (0.001, 0.01) [†]	0.35
Knee extensor strength	0.0002 (−0.0007, 0.001)	0.06	—	—
Physical activity	—	—	−0.004 (−0.015, 0.008)	−0.08

*Unless otherwise noted.

[†]*p* < 0.05.

BMD-FN = bone mineral density at the femoral neck; BMD-TH = bone mineral density at the total hip; B = unstandardized regression coefficient; β = standardized regression coefficient.

Table 5 Independent Predictors of Bone Mineral Density: Results from Stepwise Multiple Linear Regression for the Full Sample

Variable	BMD-FN (<i>n</i> = 81), B (95% CI)*	BMD-TH (<i>n</i> = 82), B (95% CI)*
Model summary		
<i>R</i> ²	0.17 [†]	0.12 [†]
Adjusted <i>R</i> ²	0.16	0.10
SE	0.11	0.12
Coefficients		
Constant	0.69 (0.003, 0.008)	0.73 (0.64, 0.82)
Grip strength	0.006 [†] (0.62, 0.77)	0.006 [†] (0.002, 0.009)

*Unless otherwise noted.

[†]*p* < 0.05.

BMD-FN = bone mineral density at the femoral neck; BMD-TH = bone mineral density at the total hip; B = unstandardized regression coefficient.

factors in two age groups of women, is presented in Table 6. The regression analysis revealed that balance alone explained 10% (*R*² = 0.10; *F*_{1,40} = 4.57; *p* = 0.038) of the total variability in BMD-FN among women aged 50–64 years with DRF. Handgrip strength was identified as the independent variable, explaining 32% (*R*² = 0.32; *F*_{1,23} = 10.78; *p* = 0.003) of the total variability in BMD-FN among those aged 65–80 years.

However, modifiable risk factors were omitted from the regression model at *p*_e < 0.05 and *p*_r > 0.06 and were not able to explain variability in BMD-TH when the sample of women with DRF was stratified by age. On using *p*_e < 0.05 and less stringent *p*_r > 0.1, we noted similar findings between the two bone testing sites; both balance (*R*² = 0.07; *F*_{1,41} = 3.48; *p* = 0.07) and handgrip strength (*R*² = 0.14; *F*_{1,23} = 3.79; *p* = 0.06) were revealed as indepen-

Table 6 Independent Predictors of Bone Mineral Density at the Femoral Neck: Results from Stepwise Multiple Linear Regression in the Age-Stratified Sample of Women

Variable	50–64 y (<i>n</i> = 42), B (95% CI)*	65–80 y (<i>n</i> = 25), B (95% CI)*
Model summary		
<i>R</i> ²	0.10 [†]	0.32 [†]
Adjusted <i>R</i> ²	0.08	0.29
SE	0.09	0.10
Coefficient		
Constant	0.78 (0.71, 0.84)	0.45 (0.23, 0.67)
Balance	0.03 [†] (0.001, 0.06)	—
Grip strengths	—	0.02 [†] (0.006, 0.03)

Note: Age group 50–64 years: BMD-FN = 0.78 + 0.03 (balance); age group 65–80 years: BMD-FN = 0.45 + 0.02 (grip strength).

*Unless otherwise noted.

[†]*p* < 0.05.

BMD-FN = bone mineral density at the femoral neck; B = unstandardized regression coefficient.

dent predictors of BMD-TH in women aged 50–64 years and women aged 65–80 years with DRF, respectively. We were underpowered to conduct an age-stratified stepwise regression analysis for a male-only sample.

The post hoc power analysis indicated that the power of correlational analysis ranged from 83% to 99% for all variables except for the relationship of BMD with the RAPA (power = 10%) and the PRWE (power = 7%). For stepwise multiple regression analyses conducted using five predictors (three were modifiable—grip strength, balance, and knee extensor strength—and two were non-modifiable—age and gender), we were fully powered to provide evidence to determine the independent predictor

of BMD-FN (power = 87%) but fell below the target level of 80% for BMD-TH (power = 69%). Also, we were not fully powered to investigate independent predictors of BMD-FN for the age-stratified, women-only sample with DRF (for women aged 50–64 years, power = 37%; for women aged 65–80 years, power = 22%). For a fully (80%) powered study with moderate effect size (0.15), we were in need of 92 subjects for the whole sample and 77 subjects for each age-stratified, women-only sample.

DISCUSSION

The results of this study identified that reduced handgrip strength and poor postural balance were related to BMD in people with a recent DRF, and the influence of these factors varied in women aged 50–64 years and 65–80 years. Although this relationship was observed at one point in time, it is important to note that both these factors are modifiable by physical therapy.

These modifiable factors have previously been shown to affect physical health, including bone health. Grip strength has been shown to have a correlation with overall muscle strength, fitness, and frailty in previous studies.^{39–41} Previous studies also showed that postural balance was related to BMD.^{42,43} Poor postural balance may be either a predictor or a consequence of inadequate PA,^{44,45} and weight-bearing PA is known to be a modifier of bone density.⁴⁶ Thus, we expect these that variables act indirectly on bone density. Our study adds to the literature in that we had a larger sample and used a stratified regression model to determine the independent modifiable determinants of BMD.

In support of other studies,^{47,48} we identified that advancing age is associated with reduced muscle strength and BMD. We dichotomized our participants into groups aged 50–64 and 65–80 years because substantial bone loss usually occurs in women aged about 50 years and in men aged about 65 years. When compared with men, women presented significantly lower BMD, muscle strength, and postural balance. Similar to our findings, other studies have shown that bone strength, muscle strength, and balance were poorer in women with DRF.^{17,18} In addition to anthropometric differences between men and women, the reduction in estrogen and changes in muscle architecture (an increase in non-contractile tissue such as intramuscular fat and an increase in muscle atrophy, especially of type 2 muscle fibres) with the onset of menopause could contribute to these gender-based differences.^{49,50}

Among all modifiable risk factors, handgrip strength and balance presented a significant, weak to moderate relationship with BMD at both sites. Lower extremity muscle strength was significantly related to BMD-FN but not BMD-TH. Our correlation results for the relationships of grip strength and balance with BMD are consistent

with other studies.^{43,51} In 117 physically active women aged 50 years and older, Marin and colleagues noted a moderate significant correlation ($r = 0.49–0.56$; $p < 0.001$) between handgrip strength and BMD, irrespective of the site of the BMD, whereas static balance exhibited a weak but significant positive correlation ($r = 0.24$; $p < 0.01$) with spinal bone density.⁴³

Although previous studies have shown that leg extensor muscle strength was a predictor of BMD among patients with Parkinson disease,⁵² we did not find such an association in our study. This may be because our sample was healthier and grip strength has less measurement error to diffuse the observable correlation. Because grip strength and leg extensor strength were positively correlated with one another and both represent overall muscle strength, it appears that leg strength did not significantly contribute any further explanation of the variability in BMD than grip strength.

PA was not associated with BMD-FN, yet it was associated with BMD-TH. The negative relationship of PA with BMD in our study was contradictory to the literature.^{53,54} Studies have suggested that skeletal loading during PA, due to either weight bearing against gravity or the traction forces applied by the muscles on the bone, increases dynamic stress on the bone tissue.^{53,54} As a subsequent biological response, the downstream effect of this increased stress is an increase in BMD.^{55–59} However, in most of these studies, PA levels were measured in either adolescent girls or young adult men; one study⁵⁸ was done on elderly women.

We must acknowledge that the outcome measure used to evaluate PA in our study has been shown to exhibit lower reliability estimates (intra-class correlation coefficient = 0.68)⁶⁰ and has not been specifically validated for people with DRF. Moreover, the RAPA is a short nine-item questionnaire, and it might not reflect the wide range of PA engaged in by older adults with DRF; this might have also biased our findings.

Similarly, it was interesting to note the lack of a significant relationship between fracture-specific pain and disability and BMD. Although pain and disability are important outcomes, they do resolve within 6 months for the majority of patients with DRF;^{61,62} this may be why they do not show an impact on BMD. Overall, we found that handgrip strength was the only factor that independently explained the variability in BMD in a complete sample of people with DRF. This finding was similar to those of previous studies.^{63–65} It was interesting that there was no difference in the modifiable determinants of BMD, irrespective of whether the BMD site was at FN or TH.

In stratifying our sample to control for the known confounders of age and gender, balance and handgrip strength explained 10% and 32% of the variability in

femoral BMD in women aged 50–64 and 65–80 years, respectively. We believe that postural balance could explain the variability in BMD, based on the fact that it might cause body weight to shift away from the centre of gravity; such a shift can lead to less weight bearing on the bones. Given that weight bearing on the bones has an impact on BMD, reduced weight bearing on the bones may in turn result in reduction in the BMD. Future studies must investigate whether postural balance remains an independent predictor of BMD in a body weight-adjusted sample of people with DRF.

Previous research has identified the association of balance impairment with low BMD among postmenopausal women.^{42,66} Recently, Mehta and colleagues established a high reliability for the timed up-and-go test to assess functional balance among patients with DRF (with a mean age of 62.6 [SD 7.6] y).⁶⁰ This is likely a more feasible test for clinical implementation than the Biodex data we used for our research purposes.

Similar to the findings seen in our study, Monaco and colleagues reported that handgrip strength explained 33% of the variability in distal radius BMD among 102 postmenopausal women aged 50–80 years.⁶³ In other studies, handgrip strength has been identified as an independent predictor of hip,^{64,67} femoral, or spine BMD^{43,68} among women. Zimmerman and colleagues did not find any association between grip strength and BMD-TH among postmenopausal women;⁶⁸ however, they were underpowered to confirm a significant association. Although muscle forces have a positive influence on building bone,⁶⁹ the size and location of the grip muscles makes it unlikely to directly affect BMD at the hip or femoral neck. Rather, grip strength may be an indicator of overall muscle strength and fitness,^{39,40} or it may confound the relationship between PA and BMD. Conversely, better grip strength may allow people to engage in a more active lifestyle or occupational tasks that involve weight bearing and thus could be indirectly related to better bone health.

Our data did not explain the mechanism or direct cause-and-effect relationship between handgrip strength and the BMD reported at the distal sites (i.e., whether the relationship could be related to common genes⁷⁰ or was due to some other, unexplained factors). We might explain this association as increased compensatory physical stress, or muscle contraction on an unaffected hand resulting in localized bone formation, which could improve overall bone metabolism and thus affect the distant skeleton.⁷¹ Moreover, in many studies, handgrip strength is a determinant of functional limitation, frailty, functional decline, and mortality among older adults.^{41,72–74}

This study had a number of limitations. Because of the cross-sectional nature of the evidence, the association between handgrip strength and BMD cannot be inter-

preted as causal. Future prospective research should investigate the temporal relationship between wrist-hand muscle and bone to determine whether an exercise programme that incorporates upper and lower extremity strengthening could improve BMD among patients with DRF. Given that grip strength of the unaffected hand explained only 12%–17% of the variability in BMD for the whole sample, these findings must be considered with caution in clinical practice. Future studies should consider including other relevant modifiable clinical risk factors, such as vitamin D intake and diet, comorbidity, frailty, exposure to weight-bearing exercise, and BMD.

Despite these limitations, this study addressed a novel issue and provided an important perspective for physical therapists evaluating unaffected handgrip strength as part of the routine clinical assessment of patients with DRF. Therapists might consider evaluating grip strength of the unaffected hand and comparing it with normative values to identify those patients who might benefit from BMD testing.

Our age-stratified results are limited to women with DRF, and this restriction facilitates the internal validity of our findings. We strongly recommend that subsequent studies focus on identifying the modifiable determinants of BMD among men. Future studies must be conducted on a large sample to validate the preliminary findings established in this study and to determine a potential cut-off value for grip strength and balance scores; such a value could identify patients at risk of secondary OP and subsequent fractures after a recent DRF. Moreover, we have discussed the association of modifiable risk factors with BMD in patients with recent DRF (1–2 weeks after DRF).

Previous studies have demonstrated lower muscle strength, balance, and physical performance among patients 6–24 months after DRF, and these patients were compared with those without DRF.^{15,17,18} In the future, studies should evaluate whether there are any differences in muscle strength, balance, and PA among persons with recent DRF and normative age- and gender-matched controls or those with no DRF. Future research could also consider the association of modifiable risk factors with BMD among persons with recent DRF and those 12 months after DRF.

CONCLUSIONS

Unaffected handgrip strength and postural balance are modifiable factors associated with BMD among persons with recent DRF. Therapists should consider these factors as important indicators of bone health, particularly when they do not have access to BMD data. This supports the inclusion of upper and lower body strengthening and balance to promote bone health. However, longitudinal studies and direct comparisons of different exercise approaches and trials are needed.

KEY MESSAGES

What is already known on this topic

Distal radius fracture (DRF) is an early and independent predictor of secondary osteoporotic (OP) fractures, and the majority of older people with DRF present with low bone mineral density (BMD). Factors that are modifiable by physical therapy can potentially have an impact on bone health.

What this study adds

This study adds the finding that unaffected handgrip strength, evaluated at 3 months post fracture, is associated with BMD at the time of DRF. Postmenopausal women with low grip strength should be considered at higher risk and may need more detailed bone health assessment and secondary OP fracture prevention.

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