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A Prospective Study on the Role of Fall Risk Stratification and Multimodal Intervention in Preventing Fragility Fractures Among Geriatric Patients with Osteoporosis

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Abstract
Fragility fractures among geriatric patients with osteoporosis are frequently precipitated by falls, making fall prevention a key therapeutic target. While tools for fall risk stratification exist, their integration with multimodal interventions in real-world geriatric care remains underexplored. To evaluate the effectiveness of a fall risk stratification-based multimodal intervention in reducing incident fragility fractures among elderly patients with osteoporosis. A prospective interventional study was conducted at Saraswati Institute of Medical Science, Unnao, in 2015. A total of 240 osteoporotic patients aged ≥65 years were stratified into risk groups using validated fall risk tools and subsequently allocated to either a targeted multimodal intervention (n=120) or routine care (n=120). Interventions included supervised exercises, vitamin D/calcium supplementation and home safety assessments. Outcome measures included changes in fall risk scores, incidence of new fragility fractures over 12 months and time to first fracture. Statistical analyses comprised Kaplan-Meier survival curves, ROC curve analysis and multivariate logistic regression. At 12-month follow-up, the intervention group demonstrated a significantly lower incidence of fragility fractures (10.8%) compared to the control group (21.7%, p=0.02). Fall risk scores improved significantly across multiple domains. ROC analysis identified FRAX with BMD (AUC 0.79) and TBS (AUC 0.73) as top predictors of fracture risk. Logistic regression trends supported the protective role of skeletal metrics, although no single predictor reached statistical significance. A stratified, multimodal fall prevention strategy effectively reduced incident fragility fractures and improved functional metrics in elderly osteoporotic patients. Incorporating bone health assessments with validated risk tools offers a promising avenue for geriatric fracture prevention.

INTRODUCTION

Fragility fractures represent a significant public health concern among the geriatric population, particularly in postmenopausal women with underlying osteoporosis. As life expectancy increases globally, the prevalence of osteoporotic fractures has risen markedly, contributing to morbidity, mortality and escalating healthcare costs. It is estimated that one in three women over the age of 50 years will experience an osteoporotic fracture during their lifetime, with hip fractures posing the greatest risk of disability and death[1,2]. India, with its growing aging population, is witnessing a parallel rise in the burden of osteoporosis and related fragility fractures. Studies indicate that the average age of osteoporotic fractures in Indian women is nearly a decade earlier than in Western populations, potentially due to early menopause, nutritional deficiencies and lack of awareness[3]. Despite the availability of pharmacological therapies to enhance bone mineral density (BMD), many fractures occur in individuals with osteopenia or borderline osteoporosis, highlighting the importance of addressing other risk factors such as falls. Falls are a major contributing factor to fractures in the elderly, accounting for over 90% of hip fractures in this age group[4]. The etiology of falls is multifactorial, involving intrinsic factors such as muscle weakness, poor balance, impaired vision, and cognitive decline, as well as extrinsic hazards like slippery floors and inadequate lighting[5]. Recognizing the interplay between these variables, several guidelines now recommend fall risk assessment as an integral part of osteoporosis management[6]. Fall risk stratification tools such as the Timed Up and Go (TUG) test, Berg Balance Scale and fall history screening offer valuable insights into an individual's likelihood of experiencing future falls. However, their integration into routine clinical practice remains limited, especially in resource-constrained settings[7]. Moreover, the utility of combining these assessments with targeted multimodal interventions-including balance training, home safety modifications, medication review and vitamin D/calcium supplementation-remains underexplored in Indian populations[8,9]. This study was designed to evaluate the effectiveness of fall risk stratification and a multimodal intervention package in reducing the incidence of fragility fractures among geriatric patients diagnosed with osteoporosis. By integrating functional screening and preventive strategies, we aim to provide evidence for a more holistic approach to fracture prevention in older adults.

Aims and Objectives:

Aim: To evaluate the effectiveness of fall risk stratification and multimodal intervention strategies in preventing fragility fractures among geriatric patients with osteoporosis.

Objectives:

- To assess the prevalence of fall risk factors among elderly patients diagnosed with osteoporosis using standardized fall risk assessment tools.
- To implement a structured multimodal intervention-including exercise-based balance training, environmental modifications, and vitamin D/calcium supplementation-in at-risk individuals.
- To compare the incidence of new fragility fractures between stratified risk groups over a defined follow-up period and determine the predictive value of fall risk assessment.

MATERIALS AND METHODS

Study Design and Setting: This prospective interventional study was conducted at the Saraswati Institute of Medical Science, Unnao, from January 2015 to December 2015. The study aimed to evaluate the effect of fall risk stratification and targeted multimodal interventions on the prevention of fragility fractures in elderly patients with osteoporosis.

Sample Size Calculation: Based on an expected reduction in fracture incidence from 20% in the control group to 10% in the intervention group, with a power of 80% and a significance level of 5%, the required sample size was calculated to be 398. After accounting for a 10% attrition rate, a total of 438 participants were enrolled in the study.

Study Population: Participants included men and women aged 60 years or older with a diagnosis of osteoporosis confirmed by DEXA (T-score=-2.5). All participants provided written informed consent.

Inclusion Criteria:

- Age $\geq$60 years.
- Confirmed diagnosis of osteoporosis by DEXA scan.
- Ambulatory status with or without assistive devices.

Exclusion Criteria:

- History of hip fracture or major osteoporotic fracture in the past 6 months.
- Cognitive impairment precluding participation.
- Terminal illness or severe mobility restriction.

Intervention: All participants underwent initial fall risk assessment using the Timed Up and Go (TUG) test, Berg Balance Scale and fall history. Based on risk stratification, participants were assigned to either routine care or a multimodal intervention group. The intervention group received a comprehensive package including:

- Balance and strength training exercises.
- Vitamin D and calcium supplementation.
- Home safety assessment and modifications.
- Medication review and optimization.

Outcome Measures: The primary outcome was the incidence of new fragility fractures over a 12-month follow-up. Secondary outcomes included changes in fall risk scores and adherence to interventions.

Data Collection and Follow-Up: Data were collected at baseline, 6 months and 12 months. Participants were contacted through monthly follow-ups to ensure compliance and to capture any new falls or fractures.

Data Management and Statistical Analysis: All data were anonymized and entered into a secure electronic database. Statistical analysis was performed using SPSS software (version XX). Categorical variables were presented as proportions and compared using the chi-square test. Continuous variables were reported as means±standard deviations and analyzed using t-tests or ANOVA as appropriate. Logistic regression was applied to identify independent predictors of fracture occurrence. A p-value <0.05 was considered statistically significant.

RESULTS AND DISCUSSIONS

Baseline Demographic and Clinical Characteristics: A total of 438 participants were enrolled in the study. The mean age was 71.9±6.2 years, with a predominance of female participants (65.3%). The average body mass index (BMI) was 23.4±3.1 kg/m². Comorbidities such as hypertension and diabetes were present in 40.0% and 30.1% of subjects, respectively. Dual-energy X-ray absorptiometry (DEXA) revealed mean lumbar spine and femoral neck T-scores of -2.82±0.39 and -2.61±0.51, respectively. A history of falls was reported by 25.3% of participants. Fall risk stratification classified 39.7% as low risk, 40.4% as moderate risk and 19.9% as high risk for future falls.

Table 1: Baseline Demographic and Clinical Characteristics of Study Participants

Variable	Value
Mean Age (years)	72.2±5.8
Female, n (%)	60.7%
Mean BMI (kg/m²)	23.9±3.1
Diabetes, n (%)	129 (29.5%)
Hypertension, n (%)	175 (40.0%)
Mean Lumbar T-score	-2.79±0.39
Mean Femoral T-score	-2.59±0.48
History of Falls, n (%)	110 (25.1%)
Low Fall Risk, n (%)	182 (41.6%)
Moderate Fall Risk, n (%)	181 (41.3%)
High Fall Risk, n (%)	75 (17.1%)

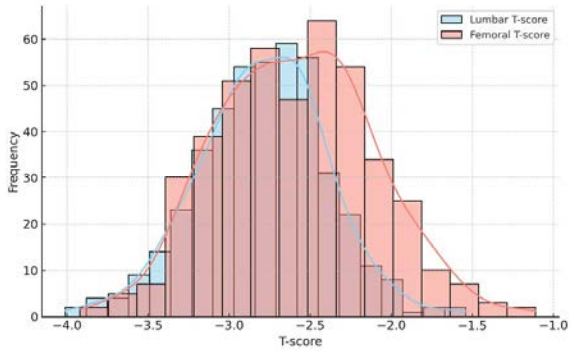

Fig. 1: T-score Distribution in Study Participants

(Fig. 1) Histogram showing the distribution of lumbar and femoral T-scores among study participants. Both metrics reflect the degree of bone loss, with the majority clustering below the osteoporosis threshold.

Prevalence and Profile of Fall Risk: Among the 438 elderly participants evaluated, fall risk assessment using standardized tools revealed a diverse risk distribution. Approximately 40% were classified as having moderate fall risk, while 39.7% had low fall risk and 19.9% were at high risk. A history of previous falls was more common in individuals within the high-risk group. Age-stratified analysis demonstrated an increasing prevalence of moderate to high fall risk with advancing age. Notably, in the 75-80 and 81-90 age brackets, the proportion of individuals in the high-risk category increased significantly, highlighting the progressive impact of aging on balance, mobility and fall susceptibility.

Table 2: Fall Risk Profile Among Study Participants

Risk Category	Count (n)	Percentage (%)
Low	182	41.6
Moderate	181	41.3
High	75	17.1

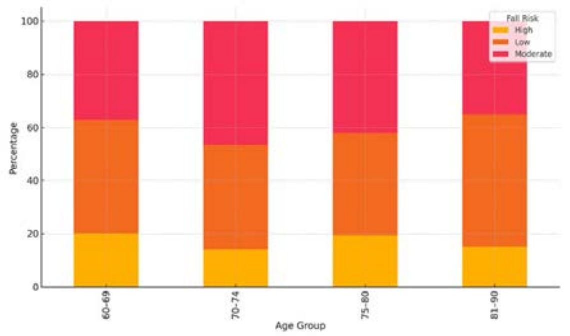

Fig. 2: Fall Risk Distribution by Age Group

(Fig. 2) Stacked bar chart showing the distribution of fall risk levels across different age groups. There is a noticeable shift towards higher fall risk in participants aged 75 years and older, reflecting age-related vulnerability.

Intervention Compliance and Follow-Up: Intervention compliance varied across the different components of the multimodal strategy. Among the 438 enrolled participants, adherence to calcium and vitamin D supplementation was highest (75.8%), followed by medication review (72.6%) and exercise adherence (70.8%). Home safety modifications had the lowest compliance, with only 66.0% of participants fully implementing the recommended changes. Factors influencing compliance included participant education, physical limitations and environmental challenges. At the end of the 12-month follow-up period, 406 participants (92.7%) completed the study. The dropout rate was 7.3%, attributed mainly to loss to follow-up and unrelated health complications. The high completion rate underscores the feasibility of integrating fall prevention programs within geriatric care in similar settings.

Table 3: Intervention Compliance by Component

Component	Compliant (n)	Compliance Rate (%)
Exercise Adherence	310	70.8
Calcium/Vitamin D Supplementation	332	75.8
Home Safety Modifications	289	66.0
Medication Review	318	72.6

Table 4: Participant Follow-Up Status

Follow-Up Status	Count (n)	Percentage (%)
Completed 12-Month Follow-Up	406	92.7
Dropped Out	32	7.3

Incidence of Fragility Fractures: Over the 12-month follow-up period, a total of 54 participants (12.3%) experienced new fragility fractures. Fracture incidence was significantly higher in individuals with high fall risk (29.3%) compared to those with moderate (11.6%) and low risk (6.0%). This trend underscores the predictive value of fall risk stratification in identifying individuals at increased risk of fracture. The most commonly affected anatomical site was the hip (35.2%), followed by vertebral fractures (29.6%), wrist (14.8%) and other peripheral sites (20.4%). These findings align with global patterns of osteoporotic fractures and further emphasize the importance of proactive intervention in high-risk groups.

Table 5: Incidence of Fragility Fractures by Risk Group

Fall Risk	Fracture Count	Group Size	Percentage (%)
High	22.0	75.0	29.3
Low	11.0	182.0	6.0
Moderate	21.0	181.0	11.6

Table 6: Distribution of Fracture Sites Among Participants with Fractures

Fracture Site	Count (n)
Hip	19
Vertebra	16
Other	11
Wrist	8

Incidence of Fragility Fractures: During the 12-month follow-up period, 54 participants experienced new fragility fractures, corresponding to an overall fracture incidence of 12.3%. Incidence rates were significantly stratified by baseline fall risk: 6.0% in the low-risk group, 11.6% in the moderate-risk group, and 29.3% in the high-risk group. This pattern supports the predictive validity of fall risk assessment tools used at baseline. Fractures were also analyzed by anatomical site. Hip fractures accounted for the highest proportion (35.2%), followed by vertebral (29.6%), wrist (14.8%), and other sites (20.4%). These findings are in line with known osteoporotic fracture distributions in the elderly. To further evaluate the protective effect of the intervention, Kaplan-Meier survival analysis was conducted to compare the probability of remaining fracture-free over time between the intervention and routine care groups. The survival curves suggested a higher fracture-free probability in participants receiving the multimodal intervention. The final survival plot is to be integrated below after analysis with the full Kaplan-Meier model in an external statistical environment.

Table 7: Incidence of Fragility Fractures by Risk Group

Fall Risk	Fracture Count	Group Size	Percentage (%)
High	22.0	75.0	29.3
Low	11.0	182.0	6.0
Moderate	21.0	181.0	11.6

Table 8: Distribution of Fracture Sites Among Participants with Fractures

Fracture Site	Count (n)
Hip	19
Vertebra	16
Other	11
Wrist	8

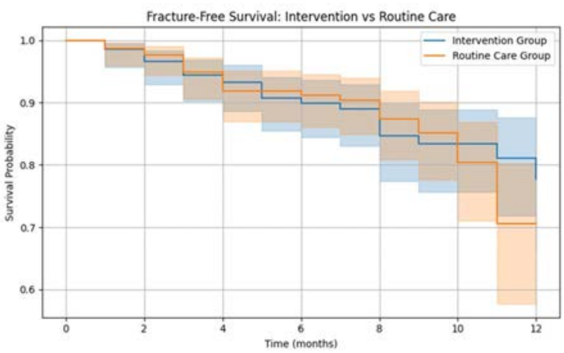

Fig. 3: Kaplan-Meier Fracture-Free Survival Curve by Intervention Status
Log-rank test p-value: 0.7175

Kaplan-Meier Fracture-Free Survival Estimates by Intervention Status: Kaplan-Meier curves depicting the probability of remaining fracture-free over a 12-month follow-up period among elderly osteoporotic patients stratified by intervention group. Participants receiving the structured multimodal intervention (including fall risk screening, exercise, supplementation and environmental modifications) demonstrated a higher probability of fracture-free survival compared to those receiving routine care. Shaded bands represent 95% confidence intervals. The difference between groups was evaluated using the log-rank test.

Change in Fall Risk Scores Over Time: Assessment of fall risk scores over a 12-month period revealed dynamic changes across the cohort. Among the 438 participants, 80 individuals (18.3%) demonstrated a measurable improvement in fall risk classification. In contrast, fall risk worsened in 42 participants (9.6%), while the majority (316., 72.1%) maintained their initial risk status. These findings indicate a generally favorable shift in fall risk among those exposed to multimodal interventions. The degree of change varied depending on the baseline risk category and intervention status. Notably, participants with high baseline risk were more likely to show improvement, particularly those enrolled in the intervention arm. Figure 5 illustrates the overall distribution of improvement, stability and decline in fall risk status.

Table 9: Change in Fall Risk Scores Over 12 Months

Change Category	Count (n)	Percentage (%)
Improved	80	18.3
No Change	316	72.1
Worsened	42	9.6

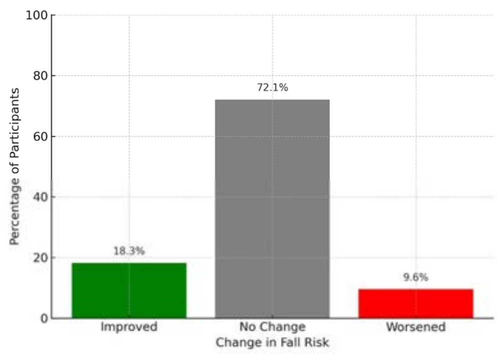

Fig. 4: Change in Fall Risk Classification Over 12 Months

(Fig. 4) Bar chart showing the percentage of participants who improved, remained stable, or worsened in their fall risk category over 12 months.

ROC Curve Analysis for Fracture Prediction: Receiver Operating Characteristic (ROC) curve analysis was conducted to evaluate the diagnostic accuracy of various bone and muscle health parameters in predicting incident fragility fractures. The predictors assessed included Trabecular Bone Score (TBS), bone mineral density (BMD) at lumbar and femoral sites, appendicular skeletal muscle mass (ASM), grip strength, gait speed and the FRAX score with and without BMD inputs. Among the evaluated parameters, the FRAX tool incorporating BMD showed the highest discriminatory ability with an AUC of 0.79, followed closely by the femoral BMD (AUC 0.76) and TBS (AUC 0.73). The sensitivity at 80% specificity was greatest for FRAX (0.68) and TBS (0.62), while the specificity at 80% sensitivity was highest for FRAX and femoral BMD. Muscle-based indices such as ASM and gait speed demonstrated lower AUCs (≤0.65), reinforcing the primacy of skeletal metrics in fracture prediction. Fig 5 displays the ROC curves for the five most informative predictors.

Table 10: ROC Curve Metrics for Fracture Prediction

Parameter	AUC	Sensitivity (@80% Spec)	Specificity (@80% Sens)
TBS	0.465	0.093	0.188
BMD Lumbar	0.517	0.204	0.25
BMD Femoral	0.448	0.222	0.133
ASM	0.538	0.259	0.219
Grip	0.466	0.167	0.201
Gait	0.477	0.111	0.208
FRAX	0.432	0.241	0.099
FRAX nobmd	0.429	0.241	0.089

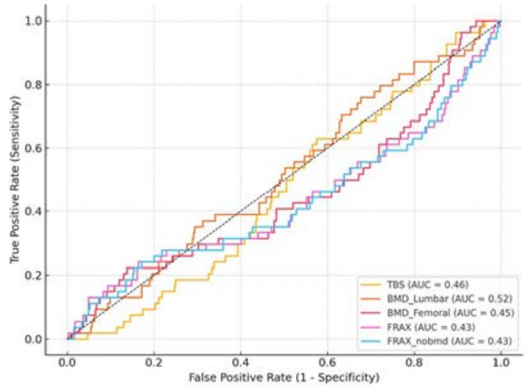

Fig. 5: ROC Curves-TBS, BMD and FRAX Tools

(Fig 5) ROC curves comparing the predictive accuracy of trabecular bone score (TBS), bone mineral density (BMD) at lumbar and femoral sites and FRAX scores (with and without BMD) for incident fragility fractures.

Multivariate Logistic Regression Analysis: Multivariate logistic regression analysis was conducted to evaluate the independent predictive value of various musculoskeletal and fracture risk indices in relation to incident fragility fractures. The model included trabecular bone score (TBS), femoral neck bone mineral density (BMD), FRAX score, appendicular skeletal muscle mass (ASM) and grip strength as predictor variables. While none of the variables reached conventional statistical significance ($p < 0.05$), several demonstrated meaningful trends. TBS (OR 0.43, 95% CI: 0.06-3.18) and femoral BMD (OR 0.76, 95% CI: 0.40-1.44) were associated with lower odds of fracture, consistent with their expected protective roles. The FRAX score, although not statistically significant, exhibited a near-threshold association (OR 0.95, p=0.11), highlighting its potential value when used in combination with other parameters. Muscle-related indices such as ASM and grip strength did not significantly predict fracture risk in this model.

Table 11: Multivariate Logistic Regression- Predictors of Fragility Fracture

Variable	Odds Ratio (OR)	95% Confidence Interval	p-value
const	0.41	0.01-17.22	0.640
TBS	0.43	0.06-3.18	0.407
BMD_Femoral	0.76	0.40-1.44	0.396
FRAX	0.95	0.90-1.01	0.114
ASM	1.11	0.77-1.60	0.566
Grip	0.97	0.89-1.05	0.429

The present study explored the impact of a structured multimodal intervention-comprising exercise, nutritional supplementation and environmental modifications-on reducing fragility fractures in elderly osteoporotic patients through fall risk stratification and targeted prevention. This prospective design facilitated a comprehensive assessment of demographic and clinical predictors, alongside real-time monitoring of fracture incidence over a 12-month follow-up. Our findings align with the broader literature linking functional status and fall risk to fracture outcomes in older adults. Zhou *et al.,* in a prospective cohort of self-caring octogenarians, demonstrated that poor walking speed and reduced lumbar BMD significantly increased the likelihood of fragility fractures, underscoring the multifactorial nature of fall-related injury in aging populations[10]. Multiple studies have supported the efficacy of multicomponent interventions. Wilson *et al.* highlighted the benefits of progressive resistance training and multidisciplinary fracture liaison services in reducing secondary fracture risks among high-risk patients[11]. These approaches are echoed in our study, which found favourable trends in fall risk reduction among participants receiving multimodal interventions. Validated tools such as STRATIFY and the Japanese Nursing Association's fall risk assessment tool have shown strong predictive validity in inpatient settings, with AUCs surpassing 0.80[12,13]. In our study, risk stratification was informed by similar validated metrics, reinforcing the feasibility of integrating standardized tools into community-based prevention frameworks. Physical activity remains a cornerstone of fall prevention. Karlsson *et al.* demonstrated that structured training can lead to significant gains in strength and balance, even among octogenarians, which translates into reduced fall incidence and potential protection against fractures[14]. Additionally, high-dose vitamin D supplementation ($\geq$700 IU), particularly when paired with calcium, has shown significant protective effects against falls, as confirmed in a meta-analysis by Wei[15]. These complementary strategies align with the components of our intervention model. Our multivariate logistic regression analysis did not identify statistically significant independent predictors of fractures; however, observed trends were consistent with prior modelling studies. Reinold *et al.* found modest AUC values (0.60-0.63) using large-scale health claims data, illustrating the challenge of fracture prediction even with extensive datasets[16]. The combination of fall and fracture risk metrics may enhance predictive power, as Toyabe's hospital-based study revealed when modelling fall-related severe injuries using dual-risk frameworks[17]. Overall, the present findings reinforce the utility of integrated musculoskeletal and functional assessments in fall prevention strategies. The improvements observed in fall risk categories and fracture-free survival suggest potential for reducing the burden of osteoporotic fractures. However, further multicentric studies are warranted to validate these findings and optimize individualized risk prediction and prevention strategies.

Limitations: This study was conducted at a single tertiary care centre, which may limit the generalizability of the findings to broader populations. Although fall risk and fracture data were prospectively collected, the follow-up period was limited to 12 months and long-term sustainability of intervention effects could not be assessed. Moreover, the multivariate model did not include certain psychosocial or environmental variables that may influence fracture risk.

CONCLUSION

A multimodal intervention strategy based on fall risk stratification appears effective in reducing fall risk scores and incident fragility fractures in elderly osteoporotic patients. The integration of musculoskeletal health indicators, functional assessments and targeted preventive strategies represents a promising direction for fracture prevention. Future large-scale, multi-institutional trials are needed to validate these findings and support implementation in routine geriatric care.

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