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Research paper

Predictive Factors for Falls among Hospitalized Older Adults on Antihypertensive Medications in China

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Abstract

Hypertension is highly prevalent among middle-aged and older adults in China, making them particularly vulnerable to falls due to complications such as orthostatic hypotension and dizziness. Since fall prevention is a key indicator of nursing care quality, this study examined predictive factors of fall risk among hospitalized older adults receiving antihypertensive medications. A retrospective quantitative design was applied using 255 cases (1:1 ratio of fall and non-fall patients) drawn from medical records and adverse event reports of three general hospitals in Hainan Province. Logistic regression was used to analyze associations with fall risk. Results showed that 49.80% of participants experienced falls during hospitalization. Significant predictors included advanced age ($p < .001$), low body mass index ($p = .028$), high-dose antihypertensive use ($p < .001$), polypharmacy with two or more antihypertensive classes ($p < .001$), and acute duration of antihypertensive therapy ($p < .001$). Based on these factors, a fall risk prediction model was developed to support rapid clinical identification of high-risk patients. The findings provide a theoretical and practical basis for targeted nursing interventions to reduce fall incidence in older adult inpatients on antihypertensive medications.

Keywords: *Hypertension; Older Adults; Fall Risk; Antihypertensive Medications; Nursing Interventions*

1. Introduction

Population aging has emerged as a global concern, with the World Health Organization (WHO) predicting that the number of older adults will exceed 1.5 billion by 2050 (Naja et al., 2017). In China, there were more than 158 million people aged 65 and above by the end of 2017, marking the country's transition into an aging society (Hung, 2023; Zhu & Walker, 2022). Hypertension is one of the most common chronic diseases among older adults, with prevalence rates exceeding 50% and approaching 90% among those aged 80 and above (Oliveros et al., 2020). Although hypertension management has improved in recent years, awareness, treatment, and control remain suboptimal (Parati et al., 2021). In this population, complications such as orthostatic hypotension, postprandial hypotension, and circadian fluctuations in blood pressure increase the risk of dizziness and falls (Fedorowski et al., 2022).

Falls are a leading cause of injury and mortality in later life and a frequent safety event in hospitals (Trinh et al., 2020). For older adults with hypertension, autonomic dysregulation and medication-related effects (e.g., orthostatic and postprandial hypotension) compound fall risk despite improvements in hypertension management (Fedorowski et al., 2022). Evidence on antihypertensive use and falls remains mixed: some reports associate higher doses, certain classes, and regimen complexity with greater risk, whereas others find no association when exposure is measured crudely by "*any use*" (Ang et al., 2018; Banu et al., 2018). More granular exposure metrics, such as WHO-defined daily dose (DDD) and temporal patterns (initiation, up-titration) appear informative with acute changes within 0 to 24 hours, especially salient (Shimbo et al., 2016). Current fall tools widely used in China (e.g., Morse, Hendrich, Johns Hopkins) show variable accuracy and rarely account for antihypertensive class, dose, and duration simultaneously. Hence, there is a clear need for a parsimonious, medication-aware model tailored to hospitalized older adults with hypertension.

The current study addresses these gaps by (*1*) quantifying inpatient fall risk among older adults with hypertension using detailed medication exposure (class, DDD, and duration/acute change) alongside core patient factors (age, gender, BMI, weight, height) and (*2*) developing a parsimonious, medication-aware prediction model tailored to hospitalized older adults. Using real-world data from three large general hospitals in Hainan Province, China, from the year 2016 to 2023. Hence, the current study seeks to provide an empirically grounded tool to support early identification and targeted prevention in routine nursing care.

Theoretical Framework - The current study is anchored in three complementary nursing theories that collectively justify a patient-centered, medication-aware fall-prevention strategy. First, Orem's (2001) *Self-Care Theory* positions fall prevention as support for therapeutic self-care when older adults experience self-care deficits precipitated by antihypertensive effects (e.g., dizziness, blood pressure variability). When self-care capacity is insufficient relative to self-care demands, nursing systems (education, supervision, environment modification, and/or medication timing guidance) are mobilized to restore safety (Tanaka, 2022; Yip, 2021). Second, is Roy's (1988) The *Adaptation Model* conceptualizes antihypertensive exposure and hospital context as stimuli requiring integrated physiologic and psychosocial adaptation (Callis, 2020). Falls reflect failed adaptation in regulator/cognator processes (balance, attention, confidence, mobility). Identification of high-risk medication states (e.g., initiation, dose escalation, high DDD) allows targeted interventions to enhance adaptive responses. Lastly, Pender's (2011) *Health Promotion Model* emphasizes behavior-specific cognitions, such as perceived risk, self-efficacy, and perceived barriers, that nursing actions can modify to sustain fall-preventive behaviors during hospitalization (e.g., assisted ambulation after dose changes, hydration strategies, orthostatic precautions). Together, these frameworks inform the selection of predictors, the structure of the prediction model, and the translation of risk scores into tailored nursing actions.

A medication-aware fall-risk model has numerous values. For patients and families, individualized risk communication enables practical safeguards and shared decision-making around the timing of mobilization and monitoring after medication changes. For nurses and physicians, the model supports triage (who needs closer observation and when), safer scheduling of dose adjustments, and targeted interventions beyond generic fall bundles. Hospital administrators can deploy the model to reduce adverse events, optimize staffing around high-risk windows, and strengthen nursing quality indicators. Policy makers may refine clinical guidance for antihypertensive management in older inpatients by incorporating dose and timing considerations. Finally, researchers should gain a standardized exposure framework (class, DDD, acute versus maintenance use) for comparative effectiveness studies and external validation.

Overall, the current study aimed to (*1*) determine predictive factors for inpatient falls among older adults receiving antihypertensive medications and to develop a practical risk-prediction model. (*2*) Describe participants by age, gender, BMI, weight, height, antihypertensive class, DDD, and duration/acute change. (*3*) Estimate fall incidence across these profile variables. (*4*) Assess bivariate associations between inpatient falls and: age, gender, BMI, weight, height, antihypertensive class, DDD, and duration/acute change. (*5*) Identify independent predictors of inpatient falls using logistic regression. (*6*) Develop and report a medication-aware fall-risk prediction model integrating class, dose, and duration with key patient factors.

The scope of the study is as follows: A retrospective study of 255 older inpatients (≥60 years old) with hypertension from three large general hospitals in Haikou, Hainan Province, China (January 2016 to December 2023). Cases with documented inpatient falls were matched 1:1 to non-fall controls. Exposures included antihypertensive class, DDD, and duration/acute change, alongside age, gender, BMI, weight, and height. Outcomes were ascertained from electronic medical records and adverse-event reporting systems. Inclusion required hypertension (SBP ≥140 mmHg or DBP ≥90 mmHg), inpatient status, and documented antihypertensive use. The limitations of the study are as follows: (*1*) The single-city, hospital-based, retrospective design may limit generalizability and preclude causal inference. (*2*) Residual confounding is possible from non-antihypertensive medications that increase fall risk (e.g., antidepressants, antipsychotics) and from multimorbidity, as several antihypertensive classes are used for other cardiovascular conditions. (*3*) Measurement error in routine data and variability in fall reporting may affect precision. (*4*) The model requires external and prospective validation, including assessment of calibration, discrimination, and clinical utility (e.g., decision-curve analysis).

2. Literature Review

Falls among older adults represent a complex global health challenge, characterized by high morbidity, mortality, and escalating healthcare expenditures (Ribeiro et al., 2018). The risk is particularly pronounced within the hospital setting, wherein patient falls are the most common type of inpatient accident. These events frequently necessitate medical attention, which results in serious injuries and leads to adverse patient outcomes (Liu et al., 2023; Shuto et al., 2010). Indeed, inpatient falls are estimated to prolong the average hospital length of stay by approximately 6.3 days (Ribeiro et al., 2018). Consequently, effective fall prevention strategies are recognized as a core indicator of quality nursing and healthcare (Rhalimi et al., 2009).

The study population, consisting of hospitalized older adults receiving antihypertensive medications, faces heightened fall vulnerability due to the inherent physiological changes associated with aging, high prevalence of comorbidities, and the pharmacologic effects of their treatment regimen. The findings identified in the present study, such as advanced age, low BMI, high-dose antihypertensive use, polypharmacy involving multiple antihypertensive classes, and acute duration of antihypertensive therapy, are strongly substantiated by extensive literature examining medication safety and geriatric risk factors.

2.1 Medication-related risk factors for falls

Medication use is unequivocally identified as one of the principal causes of falls, especially among the elderly (Lawson et al., 2018). They also noted that the complexity and number of medications prescribed to older adults often escalate with age. In reality, polypharmacy, frequently defined as the use of four or more prescribed medications, or specifically identified as the concurrent use of ≥5 medications, is highly prevalent in this population (Li et al., 2025). In community-dwelling older adults, the average number of medications used has been reported at 10.51, with 93.90% taking four or more prescribed medications (Lawson et al., 2018). Similarly, in a retrospective case-control study of hospitalized older adults who experienced a fall, 92% of the cases demonstrated polypharmacy (defined as ≥5 drugs) (Machado-Duque et al., 2024). The mechanism linking polypharmacy to falls is rooted in the increased risk of adverse effects, which may include dizziness, orthostatic hypotension, sedation, and confusion (Lawson et al., 2018). These adverse effects are further compounded by age-related physiological changes such as reduced renal function and altered drug metabolism.

Fall Risk-Increasing Drugs (FRIDs) - The concept of FRIDs helps categorize pharmacological agents based on their established propensity to induce falls. These medications are nearly universally prescribed to older adults with severe chronic conditions, such as those hospitalized for heart failure (HF), where FRID prevalence upon admission reached 94% (Liu et al., 2023). Although cardiovascular (CV) drugs, including antihypertensives and diuretics, are recognized as FRIDs, numerous studies indicate that they generally pose a weaker risk than medications acting primarily on the central nervous system (CNS) (Banu et al., 2018). CNS drugs, such as antipsychotics, antidepressants, anxiolytics, hypnotics, sedatives, opioids, and antiepileptics, are often associated with the greatest likelihood of causing inpatient falls (Ribeiro et al., 2018). Specific analyses using risk scoring tools, such as the Agency for Healthcare Research and Quality medication-based risk score, typically assign psychotropics 3 points (high risk), while antihypertensives score 2 points (medium risk), and diuretics score 1 point (low risk) (Kahlaee et al., 2018). However, the high prevalence of CV FRIDs means that they remain major contributing factors (Liu

et al., 2023). In a study of older adults hospitalized for HF, the majority of FRIDs taken were CV in nature (Liu et al., 2023). Antihypertensives, specifically agents acting on the renin-angiotensin system, were reported as one of the most frequently prescribed classes of medication to older adults (Lawson et al., 2018).

Acute versus chronic duration of antihypertensive therapy - The temporal relationship between initiating antihypertensive medication and the onset of fall risk is a critical finding repeatedly emphasized in the literature, strongly supporting the current study's finding regarding acute duration of therapy.

Acute risk period: Research using time-dependent study designs, such as the self-controlled case series (SCCS) and case-crossover studies, has effectively isolated the transient hazard period following treatment changes (Shimbo et al., 2016). These studies consistently show that the risk of falling is significantly elevated shortly after initiation or dose modification (Kahlaee et al., 2018). This large SCCS study examining Medicare beneficiaries aged ≥65 years found that the odds for a serious fall injury were significantly increased during the 15 days following antihypertensive medication initiation (Shimbo et al., 2016). They noted that the acute risk was similarly observed after intensifying therapy, whether by adding a new antihypertensive class or simply titrating the dosage of a current class. The association between antihypertensive initiation/intensification and serious fall injury was found to be attenuated beyond 15 days. For hospitalized patients, where the acuity of medication change may be heightened, one case-crossover study in an acute care setting found that the initial use of antihypertensive agents was strongly associated with an increased risk of falls (Shuto et al., 2010). These finding highlights the specific danger of acute duration of therapy in the vulnerable inpatient environment.

Chronic risk period: In contrast to the acute phase, research has generally shown that there is no significant increase in the risk of falls for chronic use of antihypertensive medication (defined as ≥28 days) (Kahlaee et al., 2018). They further noted that the meta-analyses focusing on chronic use often report effect sizes close to unity (i.e., no increased risk) across major classes, including ACE-i/ARBs and Calcium Channel Blockers (CCBs). This differentiation between acute and chronic exposure is crucial for appropriate clinical targeting of fall prevention interventions.

2.2 Intrinsic Patient Risk Factors

In addition to medication management, the intrinsic physical and cognitive status of the patient significantly predicts fall vulnerability. The demographic and clinical factors found to be predictive in the current study, such as advanced age, low BMI, and the presence of comorbidities, are noted to be well-established in geriatric risk assessments.

Advanced age (or old age) - As noted earlier, the risk of falls increases exponentially with age due to inevitable physiological decline. Advanced age is a critical, independent predictor of falls in various populations (Li et al., 2025). Their study focused on hospitalized older adults with hypertension; age was found to be statistically significant in predicting falls. Actually, the majority of hypertension intervention trials and observational studies that specifically investigate medication risks and falls are mostly focused on older adults, typically those aged ≥65 years (Juraschek et al., 2019).

Frailty, low BMI, and comorbidity - The concept of frailty, which represents a decline across multiple physiological systems, is far more indicative of biological age and health status heterogeneity than chronological age alone (Hu et al., 2021). They also noted that frailty assessment is deemed clinically useful for guiding the management of hypertensive patients. Frailty is robustly associated with negative health outcomes, including falls, among patients with hypertension. For hypertensive patients, the presence of frailty significantly predicted injurious falls. Furthermore, a dose-response relationship was observed, where a higher degree of frailty status (frail > prefrail > robust) was associated with a higher risk of injurious falls. Even prefrailty status and overt frailty significantly predicted all-cause hospitalization in hypertensive patients (Hu et al., 2021).

For low BMI and malnutrition, given that frailty is linked to mortality, hospitalization, and injurious falls in hypertensive patients, its identification, potentially indicated by a low BMI, warrants proactive intervention (Li et al., 2025). The prevalence of chronic diseases (comorbidities) is inherently high in the older adult population receiving complex medication regimens (Liu et al., 2023). Patients with diabetes mellitus, which is strongly associated with a higher risk of falls, often participate in studies analyzing fall risks among hypertensive populations (Canuto et al., 2020). In frail patients, low blood pressure values (potentially resulting from antihypertensive overtreatment) are related to syncope, falls, injuries, and fractures. These suggest that clinical decision-making regarding blood pressure targets must incorporate frailty assessment to prevent iatrogenic harm, particularly when multiple chronic diseases and high-risk medications are present (Banu et al., 2018; Hu et al., 2021)

2.3 Recent Studies on Hypertension, Frailty, and Falls

Across new research studies, a consistent picture emerges: hypertension rarely acts alone in elevating fall risk; it clusters with frailty, cardiovascular dysfunction, sensory-motor challenges, and cognitive changes. Community evidence shows that frailty and hypertension each relate to greater fall vulnerability, and together they compound risk (Teng et al., 2024). Broader syntheses further underline that multiple cardiovascular disorders, such as arrhythmias and orthostatic instability, are commonly linked with falls, reinforcing the need to pair blood-pressure management with cardiovascular assessment in older adults (Bourke et al., 2024). Beyond hemodynamics, recent work highlights sensory processing and movement fear as practical targets. Older adults with hypertension can exhibit reduced vestibular and visual processing, lower activity levels, and heightened fear of falling or kinesiophobia, all of which may erode balance confidence and increase avoidance behaviors (Cemali et al., 2025). While cognitive factors also matter, among adults with subjective memory concerns, falls are associated with gait changes, suggesting that cognitive-motor integration deserves routine attention in fall prevention (Delgado et al., 2024). Complementing these findings, reviews of hypertension in frail elders emphasize the difficulty of setting safe treatment targets and choosing agents, given diminished physiological reserves and competing risks (Li et al., 2024).

Taken together, these studies support a multidomain approach: screen for frailty and cardiovascular contributors alongside medication exposure; include simple sensory-balance checks and fear-of-falling measures; and consider brief cognitive and gait assessments when memory concerns are present. For hypertensive inpatients specifically, this literature strengthens the rationale for medication-aware precautions during acute treatment changes, while also advocating broader, person-centered safeguards that account for frailty, cardiovascular status, sensory integration, and cognition.

2.4 Synthesis

Taken together, the literature converges on three pillars: (*1*) medication exposure is not monolithic, for instance risk concentrates around acute initiation or intensification and around higher dose burden (e.g., DDD, multi-class regimens); (*2*) intrinsic vulnerability matters such

as advanced age, low BMI (a proxy for frailty/malnutrition), and multimorbidity amplify the impact of hemodynamic and neurocognitive side effects; and (*3*) the inpatient context intensifies hazards, as rapid medication adjustments, reduced mobility, and unfamiliar environments heighten the likelihood of imbalance and injury. Importantly, inconsistent findings in prior work often stem from crude exposure definitions ("*any antihypertensive use*"), insufficient temporal resolution (failure to distinguish acute versus maintenance phases), and limited integration of patient-level vulnerability markers. These gaps motivate a model that is both medication-aware (class, dose, timing) and person-centered (age, gender, BMI, comorbidity proxies).

This logic maps cleanly onto the theoretical framework. Under Orem's Self-Care Theory, acute medication changes create transient self-care deficits (e.g., dizziness, orthostatic intolerance) that outstrip older adults' capacity to maintain safe mobility without targeted nursing support. Roy's Adaptation Model conceptualizes medication adjustments as stimuli requiring rapid physiologic and behavioral adaptation (regulator/cognator subsystems); falls reflect failures of adaptation when postural control, attention, or confidence are perturbed by hypotension or sedation. Pender's Health Promotion Model adds the behavior-change lens: perceived risk, self-efficacy, and environmental barriers determine whether patients accept assisted ambulation, rise slowly after dosing, hydrate adequately, or request supervision during high-risk windows. Together, these theories justify a workflow in which risk is identified through precise exposure metrics and patient factors, then translated into tailored nursing actions that restore self-care, bolster adaptation, and sustain health-promoting behaviors.

Consequently, the present study specifies predictors that operationalize the synthesis: (*a*) antihypertensive class (to capture mechanistic differences), (*b*) dose burden through the use of DDD (to reflect pharmacologic load), (*c*) acute duration (initiation/intensification windows compared to maintenance), and (*d*) intrinsic factors such as age, gender, BMI, and body size, as pragmatic proxies for frailty and physiologic reserve. By nesting these variables in a single logistic model, the study moved beyond binary exposure coding and toward a clinically useful profile that flags who is vulnerable and when vulnerability peaks. This approach also clarifies implementation pathways aligned with the theories: (*1*) Orem: trigger compensatory nursing systems (assisted ambulation, orthostatic precautions, medication-time mobility holds) when predicted risk exceeds a threshold; (*2*) Roy: time-bound adaptation bundles after dose changes (vital sign/orthostatic monitoring, gait checks, environmental simplification); (*3*) Pender: micro-education at the bedside (risk cueing, sit-to-stand routines, request-for-assist norms) to raise self-efficacy and reduce barriers during the acute hazard period.

Importantly, prior syntheses (e.g., Ang et al., 2018) pool heterogeneous exposure and outcome definitions, often coding antihypertensive use as a binary variable and thereby diluting effects concentrated during initiation or dose escalation. Single-setting observational studies (e.g., Banu et al., 2018) are additionally vulnerable to confounding by indication, incomplete adjustment for fall risk-increasing co-medications, and protopathic bias when exposure timing is not modeled. These design limitations likely contribute to mixed conclusions. By resolving exposure into dose, regimen complexity, and acute versus maintenance phases within a uniform inpatient context, the present study isolates the clinically salient windows of risk that prior binary measures could not.

Finally, the synthesis supports a conceptual model for this study: antihypertensive exposure (class, DDD, acute versus maintenance) exerts direct effects on fall risk and indirectly interacts with intrinsic vulnerability (age, BMI/frailty proxy). The inpatient milieu moderates these relations through environmental and process factors (e.g., monitoring frequency, staffing, room layout). The model yields testable, practice-relevant outputs: a calibrated risk score for bedside screening, identification of high-risk windows post-medication change, and targeted, theory-consistent nursing responses. This creates a coherent bridge from evidence to theory to intervention.

3. Methodology

3.1 Design and Setting

The current study is designed as a retrospective cohort study of older inpatients receiving antihypertensive therapy across three Class-A Grade-III general hospitals in Haikou, Hainan Province, China, from January 2016 to December 2023. For risk-model development, a nested 1:1 case-control sample (fallers matched to non-fallers) drawn from the cohort (Iwagami & Shinozaki, 2022). Importantly, this investigation is a secondary analysis of routinely collected hospital data (EMR and AERS) from three tertiary hospitals in Haikou (2016 to 2023). No primary data were collected by the authors; therefore, feasibility constraints apply to variables not available in the source databases (e.g., standardized frailty scales, detailed gait/balance tests, or medication timing beyond recorded administration times). All exposures and outcomes were operationalized using fields consistently present across sites (antihypertensive class, dose, duration/acute change; falls documented in AERS/EMR). These constraints are reflected in the study limitations, and they motivate prospective validation with enriched covariates in future work.

3.2 Data Sources and Governance

Data for the current study came from each hospital's electronic medical records (EMR), including demographics, diagnoses, antihypertensive regimens, comorbidities, and concomitant medications, and from the adverse-event reporting system (AERS) for documented inpatient falls. Record linkage and extraction followed standardized scripts and cross-site quality checks.

3.3 Ethics

The study protocol was approved by the Hospital Ethics Committee (YLY [2023] No. 432) and the University of St. La Salle Ethics Committee (STUD-YIBU-002.23-24.T3.Grad). All of the data were retrospective and de-identified; the committees granted a waiver of informed consent. Data use agreements, privacy safeguards, and secure destruction procedures were implemented.

3.4 Participants

Inclusion criteria were age ≥60 years, inpatient status with hypertension (SBP or systolic blood pressure ≥140 mmHg or DBP or diastolic blood pressure ≥90 mmHg), and use of ≥1 antihypertensive during admission. Included cases are those with or without a documented fall during hospitalization; falls due to stroke or epileptic seizure were excluded. From eligible admissions, a final analytic sample of N = 255 (balanced 1:1 fall/non-fall) was selected based on a priori power analysis. Using G*Power (Faul et al., 2009) for logistic regression with $\alpha = .05$, power = .80, and an expected odds ratio of 1.378 (per prior literature), the required sample size was estimated at 255, implemented as a 1:1 fall/non-fall structure. All three hospitals maintain mature EMR/AERS infrastructures and standardized fall-management pathways, supporting reliable case ascertainment and medication exposure capture.

Table 1 shows that of the 255 older inpatients, 71% were aged 60-77.50 years and 29% were 77.60-95 years. Men comprised 59.20% of the sample (n=151) and women 40.80% (n=104). Body size indicators were broadly balanced across categories: 49% had BMI 14.33-23.39 kg/m² and 51% had BMI 23.40-62.50 kg/m²; 48.60% weighed 38-61.90 kg and 51.40% weighed 62-165 kg. Height was similarly even, with 49.80% at 143-163.49 cm and 50.20% at 163.50-178 cm. Overall, the cohort skews toward the younger-old (60-77.50) with a male majority, while BMI, weight, and height are approximately evenly split around the reported cut points; consistent with using sample-based thresholds (e.g., medians) for descriptive grouping. Importantly, among the 255 older inpatients on antihypertensives, 127 (49.80%) experienced a documented fall and 128 (50.20%) did not, which is an almost even split (proportion fallen = 0.498, 95% Confidence Interval; CI 0.437-0.559). This balanced distribution is consistent with the study's 1:1 sampling of fallers and non-fallers for model development.

Table 1: Demographic profile of the participants (N=255)

Variable	Category	*f*	*%*
Age (years)	60 - 77.50	181	71.00
	77.60 - 95	74	29.00
Gender	Male	151	59.20
	Female	104	40.80
BMI (kg/m2)	14.33 - 23.39	125	49.00
	23.40 - 62.50	130	51.00
Weight (kg)	38 - 61.90	124	48.60
	62 - 165	131	51.40
Height (cm)	143 - 163.49	127	49.80
	163.50 -178	128	50.20
Fall incidence	Yes (experienced fall)	127	49.80
	No (without / none)	128	50.20

3.5 Measures

Exposures (Medication and Patient Factors)

- Antihypertensive class: ACE inhibitors, ARBs, β-blockers, calcium-channel blockers (CCBs).
- Dose burden: WHO Defined Daily Dose (DDD) at exposure assessment; analyzed continuously and with pragmatic thresholds (e.g., DDD ≥3.0).
- Therapy timing: Acute (initiation, dose escalation, or class addition within a recent window) versus maintenance (e.g., ≥28 days). Primary acute window prespecified as 0-15 days.
- Patient factors: age, gender, BMI, weight, height.
- Comorbidities / concomitant medications: summary indicators, with attention to fall-risk-increasing drugs (FRIDs) (e.g., psychotropics, opioids, sedatives).

Outcome

- Inpatient fall (yes/no) is defined as an unintentional descent to the floor or a lower surface, documented in EMR and/or AERS. Stroke or seizure-related events were excluded from the fall outcome.

3.6 Data Collection Procedure

Designated trained personnel at each site extracted eligible records under a unified data dictionary. To ensure standardization, a stepwise quality-assurance process (Gliklich et al., 2020) was utilized: (1) central training; (2) pilot abstraction of 20 cases per site; (3) cross-site verification and retraining; (4) second pilot of 20 cases; (5) finalization of rules; (6) full extraction and reconciliation. Inclusion/exclusion adherence and de-identification were verified before analysis. In addition, the current study involves non-antihypertensive FRIDs, such as antipsychotics, antidepressants, benzodiazepines, sedative-hypnotics, opioids, and antiepileptics, which were variably recorded across sites and not consistently codified for retrospective adjustment. As such, the multivariable model prioritizes predictors with uniform availability (age, BMI, dose, number of antihypertensive classes, acute versus long-term). The study explicitly acknowledges potential residual confounding from FRIDs and multimorbidity.

3.7 Statistical Analysis

All analyses followed the study's descriptive, correlational, and predictive plan and were conducted in R. Participant characteristics and medication variables were summarized using frequencies and percentages for categorical data (e.g., gender, antihypertensive class) and means with standard deviations for numerical data (e.g., age, BMI, weight, height). To examine associations between inpatient falls and antihypertensive exposure characteristics, such as medication category, dosage, and duration of use, as well as patient factors (age, gender, BMI, weight, height). Correlation coefficients (r_s) were estimated with corresponding p-values. Variables showing $p < .05$ were taken forward for predictive modeling. A logistic regression model was then used to identify independent predictors of fall occurrence (yes/no). First, univariate logistic regressions screened potential predictors. Variables with $p < .05$ in univariate analyses, together with variables deemed statistically or clinically important, were entered into a multivariable logistic regression. Odds ratios (ORs) were reported for the univariate models and adjusted odds ratios (aORs) with p-values for multivariable models to quantify each predictor's independent association with fall risk (Cummings, 2009). Candidate predictors included age, gender, BMI, weight, height, antihypertensive medication class, dosage, and duration of use.

Model adequacy and parsimony were evaluated using deviance, Akaike Information Criterion (AIC) (Nakagawa et al., 2017), and Bayesian Information Criterion (BIC) (Schwarz, 1978), with lower values indicating better relative fit. McFadden's (1972) R^2(R^2McF to be precise) was reported as an index of explained variance. Overall model significance was assessed using the Likelihood Ratio Test (LRT) (Wilks, 1938), comparing the full model to the null model. To check stability, multicollinearity was assessed through the Variance Inflation Factor (VIF) and Tolerance; values close to 1.0 indicated no concerning collinearity among predictors (O'brien, 2007).

To enhance clinical credibility, a staged validation plan is proposed. Internal validation will apply bootstrap optimism correction to estimate discrimination (Area Under the Curve; AUC) (Iba et al., 2021) and assess calibration (slope, intercept, and calibration-in-the-large) (Hoshino et al., 2022; Stevens & Poppe, 2020), complemented by decision-curve analysis to evaluate net benefit across clinically relevant thresholds (Piovani et al., 2023). Temporal validation was used for later-year admissions (e.g., 2022 to 2023) from the same hospitals to

test performance stability over time. External validation was pursued in at least one additional province with a comparable EMR/AERS infrastructure, with recalibration (e.g., Platt scaling or intercept/slope updating) applied if required (Belsti et al., 2025).

4. Results

Table 2 shows that across the 255 inpatients, calcium channel blockers (CCBs) were the most frequently used antihypertensive class (n = 135, 52.90%), followed by angiotensin II receptor blockers (ARBs; n = 82, 32.20%) and beta-blockers (BBs; n = 77, 30.20%); angiotensin-converting enzyme inhibitors (ACEIs) were least common (n = 39, 15.30%). The complementary non-use proportions were 47.10% for CCBs, 67.80% for ARBs, 69.80% for BBs, and 84.70% for ACEIs. These distributions indicate a therapeutic pattern favoring CCBs in this cohort."

Table 2: Description of taking antihypertensive medications among participants

Antihypertensive meds	Group	*f*	%
Beta-Blockers (BBs)	Non-taking	178	69.80
	Taking	77	30.20
Calcium Channel Blockers (CCBs)	Non-taking	120	47.10
	Taking	135	52.90
Angiotensin-Converting Enzyme Inhibitors (ACEI)	Non-taking	216	84.70
	Taking	39	15.30
Angiotensin II Receptor Blockers (ARBs)	Non-taking	173	67.80
	Taking	82	32.20

Note. Medication classes are reported independently by class; totals are not mutually exclusive (patients may receive more than one class). Percentages are based on N = 255.

Table 3 shows the participants stratified by gender, with CCBs being the most frequently used class in both groups (males: n = 76, 50.30% of males; females: n = 59, 56.70% of females). ARBs and BBs were used by roughly one-third of patients in each gender (males: ARBs 32.5%, BBs 31.8%; females: ARBs 31.7%, BBs 27.9%). ACEIs were the least common and similar across genders (males 15.2%, females 15.4%).

Table 3: Antihypertensive medication use when grouped according to gender

Antihypertensive meds	Gender	*f*	%
Beta-Blockers (BBs)	Male	48	18.80
	Female	29	11.40
Calcium Channel Blockers (CCBs)	Male	76	29.80
	Female	59	23.10
Angiotensin-Converting Enzyme Inhibitors (ACEI)	Male	23	9.00
	Female	16	6.30
Angiotensin II Receptor Blockers (ARBs)	Male	49	19.20
	Female	33	12.90

Note. Counts are per class or type within gender; within-gender percentages were computed using N_{male} = 151 and N_{female} = 104 (see Table 1). Medication classes are not mutually exclusive.

By age group, CCBs were the most commonly used class in both the 60-77.50 years' group (n = 91, 50.30% within-age) and the 77.60-95 years group (n = 44, 59.50% within-age). In the older group, use of ARBs (n = 31, 41.90%) and BBs (n = 25, 33.80%) was comparatively higher, whereas ACEIs were least common (n = 4, 5.40%). In the younger-old group, BBs and ARBs were each used by roughly three in ten patients (BBs 28.70%, ARBs 28.20% within-age), and ACEIs by about one in five (19.30%). Overall percentages relative to the full sample (N = 255) are shown in Table 4.

Table 4: Antihypertensive medication use when grouped according to age

Antihypertensive meds	Age (years)	*f*	%
Beta-Blockers (BBs)	60 - 77.50	52	20.40
	77.60 - 95	25	9.80
Calcium Channel Blockers (CCBs)	60 - 77.50	91	35.70
	77.60 - 95	44	17.30
Angiotensin-Converting Enzyme Inhibitors (ACEI)	60 - 77.50	35	13.70
	77.60 - 95	4	1.60
Angiotensin II Receptor Blockers (ARBs)	60 - 77.50	51	20.00
	77.60 - 95	31	12.20

Note. Within-age percentages were calculated using $N_{60\text{-}77.5}$ = 181 and $N_{77.6\text{-}95}$ = 74 (see Table 1). Medication classes are not mutually exclusive.

Across BMI strata, Table 5 shows that CCBs were the most frequently used class (BMI 14.33-23.39: n = 69, 55.20% within-BMI; BMI 23.40-62.50: n = 66, 50.80%). BBs were used by roughly one-third in both groups (30.40% versus 30.00%). ACEIs showed similar low use across strata (15.20% versus 15.40%). Notably, ARBs were more common in the higher-BMI group (38.50%) than in the lower-BMI group (25.60%).

Table 5: Antihypertensive medication use when grouped according to BMI

Antihypertensive meds	BMI (kg/m2)	f	%
Beta-Blockers (BBs)	14.33-23.29	38	14.90
	23.40-62.50	39	15.30
Calcium Channel Blockers (CCBs)	14.33-23.29	69	27.10
	23.40-62.50	66	25.90
Angiotensin-Converting Enzyme Inhibitors (ACEI)	14.33-23.29	19	7.50
	23.40-62.50	20	7.50
Angiotensin II Receptor Blockers (ARBs)	14.33-23.29	32	12.50
	23.40-62.50	50	19.60

Note. Within-BMI percentages use N_{low} BMI = 125 and N_{high} BMI = 130 (see Table 1). Medication classes are not mutually exclusive.

Across height strata, Table 6 shows that CCBs were the most frequently used class in both groups (143-163.49 cm: *n* = 65, 51.20% within-height; 163.50-178 cm: *n* = 70, 54.70%). BBs were used by roughly one-third of shorter patients and slightly fewer taller patients (31.50% versus 28.90%). ACEIs were comparably uncommon across height groups (15.00% versus 15.60%). ARBs appeared somewhat more common among taller patients (34.40%) than shorter patients (29.90%).

Table 6: Antihypertensive medication use when grouped according to height

Antihypertensive meds	Height (cm)	*f*	%
Beta-Blockers (BBs)	143 - 163.49	40	15.70
	163.50 - 178	37	14.50
Calcium Channel Blockers (CCBs)	143 - 163.49	65	25.50
	163.50 - 178	70	27.50
Angiotensin-Converting Enzyme Inhibitors (ACEI)	143 - 163.49	19	7.50
	163.50 - 178	20	7.80
Angiotensin II Receptor Blockers (ARBs)	143 - 163.49	38	14.90
	163.50 - 178	44	17.30

Note. Within-height percentages were computed using $N_{143\text{-}163.49}$ = 127 and $N_{163.5\text{-}178}$ = 128 (see Table 1). Medication classes are not mutually exclusive.

By weight group, Table 7 shows that CCBs were the most commonly used class in both lighter (38-61.90 kg) and heavier (62-165 kg) patients (lighter: *n* = 64, 51.60% within-weight; heavier: *n* = 71, 54.20%). BBs were used at similar rates across groups (lighter: n = 37, 29.80%; heavier: *n* = 40, 30.50%). ACEIs were relatively uncommon (lighter: *n* = 21, 16.90%; heavier: *n* = 18, 13.70%). Notably, ARBs were more prevalent among heavier patients (n = 52, 39.07%) than lighter patients (*n* = 30, 24.20%)."

Table 7: Antihypertensive medication use when grouped according to weight

Antihypertensive meds	Weight (kg)	*f*	%
Beta-Blockers (BBs)	38 - 61.90	37	14.50
	62 - 165	40	15.70
Calcium Channel Blockers (CCBs)	38 - 61.90	64	25.10
	62 - 165	71	27.80
Angiotensin-Converting Enzyme Inhibitors (ACEI)	38 - 61.90	21	8.20
	62 - 165	18	7.10
Angiotensin II Receptor Blockers (ARBs)	38 - 61.90	30	11.80
	62 - 165	52	20.40

Note. Within-weight percentages use N_{light} = 124 and N_{heavy} = 131 (see Table 1). Medication classes are not mutually exclusive.

Table 8 shows the relationships between the incidence of falls and participants' background demographics. Bivariate analyses showed that falls were significantly associated with older age, lower BMI, higher antihypertensive dosage, use of ≥2 antihypertensive classes, and acute treatment phase (all $p < .05$). Specifically, fall incidence was higher in the 77.60-95 group (66.20%) than the 60-77.50 group (43.10%), χ^2 (1, N = 255) = 11.20, $p < .001$, Cramér's V = .210. Patients with lower BMI (14.33-23.39 kg/m²) had a higher fall rate (56.80%) than those with higher BMI (23.40-62.50 kg/m²) (43.10%), χ^2 (1, N = 255) = 4.80, $p = .028$, V = .137. Fall incidence rose sharply with dosage, from 25.00% in the 0.45-49.90 mg group to 71.90% in the 50-63 mg group, χ^2 (1, N = 255) = 55.80, $p < .001$, V = .468. Likewise, patients receiving ≥2 antihypertensive classes had substantially higher falls (86.30%) than those on a single class (25.50%), χ^2 (1, N = 255) = 90.40, $p < .001$, V = .596. Falls were also more common during the acute treatment window (77.20%) than long-term use (31.80%), χ^2 (1, N = 255) = 50.30, $p < .001$, V = .444. In contrast, gender, height, and weight were not significantly associated with falls (all $p > .05$).

Table 8: Relationship between incidence of fall and participants' demographics

Demographics / Fall	Category		Total	χ^2	*df*	*p*
Age (years)	60-77.50	77.60-95				
Without	103	25	128	11.20	1	< .001
With fall incidence	78	49	127			
Total (Cramer's V = .210)	181	74	255			
Gender	Male	Female				
Without	80	48	128	1.15	1	.284
With fall incidence	71	56	127			
Total	151	104	255			
BMI (kg/m2)	23.40-62.50	14.33-23.39				
Without	74	54	128	4.80	1	.028
With fall incidence	56	71	127			
Total (Cramer's V = .137)	130	125	255			
Height (cm)	143-163.49	163.5-178				
Without	65	63	128	0.10	1	.754
With fall incidence	62	65	127			
Total	127	128	255			
Weight (kg)	38-61.90	62-165				
Without	58	70	128	1.13	1	.088
With fall incidence	66	61	127			
Total	124	131	255			
Medication dosage (mg)	0.45-49.90	50-63				
Without	90	38	128	55.80	1	< .001
With fall incidence	30	97	127			
Total (Cramer's V = .468)	120	135	255			
Number of medication types	1	2 or more				
Without	114	14	128	90.40	1	< .001
With fall incidence	39	88	127			
Total (Cramer's V = .596)	153	102	255			

Duration of medication	Long-term	Acute				
Without	105	23	128	50.30	1	< .001
With fall incidence	49	78	127			
Total (Cramer's V = .444)	154	101	255			

Note. Percentages are within-category fall rates computed from table counts (e.g., 49/74 = 66.2% for older age). Cramér's V magnitudes may be interpreted as small (~.10), medium (~.30), and large (~.50) effects for 2×2 tables.

A binomial logistic regression examined independent predictors of fall status among older inpatients receiving antihypertensive therapy. Predictors entered were age, BMI, dosage, number of antihypertensive classes, and treatment duration (acute versus long-term), based on significant bivariate associations. The overall model was significant, $\chi^2(5) = 129.85$, $p < .001$, with McFadden's $R^2 = .367$ (Table 9), indicating a substantial improvement over the null model.

Table 9: Goodness-of-fit statistics for the logistic regression model

Model	R^2McF	χ^2	*df*	*p*
1	.367	129.85	5	< .001

Note: Models estimated using a sample size of N=255.

As shown in Table 10, older age (aOR = 1.044, 95% CI 1.002-1.088, $p = .034$), lower BMI (aOR = 0.895, 95% CI 0.815-0.983, $p = .020$), higher antihypertensive dosage (aOR = 1.005 per mg, 95% CI 1.003-1.007, $p = .001$), polypharmacy across antihypertensive classes (≥2 versus 1; aOR = 10.17, 95% CI 4.69-22.05, $p < .001$), and acute treatment phase (versus long-term; aOR = 3.00, 95% CI 1.43-6.30, $p = .004$) were all independently associated with higher odds of inpatient falls. Interpreted practically, the odds of falling increased by ~4.4% per additional year of age, decreased by ~10.5% per one-unit increase in BMI, rose by ~5% per additional 10 mg of dose, were about tenfold higher when ≥2 antihypertensive classes were used, and were threefold higher during the acute treatment window.

Table 10: Logistic regression coefficients for predictors of fall status

Predictor	Estimate	SE	*Z*	*p*	Odds ratio
Intercept	-2.287	1.882	-1.215	.224	0.102
BMI	-0.111	0.048	-2.320	.020	0.895
Dosage of taking medication	0.005	0.001	3.425	.001	1.005
Number of medication types	2.319	0.395	5.865	< .001	10.168
Duration of taking medications	1.098	0.379	2.897	.004	2.999
Age	0.043	0.021	2.119	.034	1.044

Notes. Estimates reflect the log-odds of "*fall*" versus "*no fall*." Multicollinearity was assessed (VIFs near 1.0), suggesting no concerning redundancy among predictors.

5. Discussions

This study set out to develop a medication-aware, patient-centered model for predicting inpatient falls among older adults on antihypertensives and to describe patterns of exposure and risk. Across 255 inpatients (49.80% with a documented fall), older age, lower BMI, higher antihypertensive dose, use of ≥2 antihypertensive classes, and acute treatment phase emerged as independent predictors in the multivariable model ($\chi^2(5)=129.85$, $p<.001$; R^2McF=.367). Bivariate results were directionally consistent: these same factors showed significant associations with fall status, whereas gender, height, and weight did not.

The final model also integrates intrinsic vulnerability (age, BMI) with pharmacologic exposure (dose, number of classes, acute versus long-term). The magnitudes are clinically meaningful: ~4% higher odds per additional year of age, ~10% lower odds per unit increase in BMI, ~5% higher odds per +10 mg dose, ~3× higher odds during the acute window, and ~10× higher odds when ≥2 classes are used concurrently. These results advance prior work by moving beyond crude "any use" measures toward granular exposure metrics (dose burden, regimen complexity, timing), clarifying why earlier findings were mixed (Ang et al., 2018; Banu et al., 2018). The particularly strong effect for polyclass regimens and for the acute phase dovetails with evidence that initiation or intensification concentrates risk in the first 2-3 weeks (Shimbo et al., 2016; Shuto et al., 2010), while longer-term maintenance often shows attenuated associations (Kahlaee et al., 2018).

Implication for practice - Overall, the model supports time-bound risk flagging (e.g., first 24-48 hours after dose change), targeted rounding, and prioritization of assisted ambulation for patients on multi-class or high-dose regimens. As a next step, converting coefficients into a simple point score with validated thresholds (and reporting AUC, calibration) would operationalize bedside use.

Alignment with theory - For Orem's Self-Care Theory, the acute exposure shifts (dose increase, added class) precipitate self-care deficits (dizziness, orthostatic intolerance), triggering the need for compensatory nursing systems (education, supervision, environment modification, medication-time mobility holds). Roy's Adaptation Model, the medication changes act as stimuli challenging regulator/cognator processes (postural control, attention, confidence). The acute-phase signal suggests transient adaptation lags. Bundled responses (orthostatic vitals, gait checks, simplified environment) specifically address this lag. While Pender's Health Promotion Model helps translate risk into micro-education (slow sit-to-stand routines, hydration cues, request-for-assist norms) targets behavior-specific cognitions (risk perception, self-efficacy, barriers), sustaining preventive behaviors during the hazard window.

To describe the participants and antihypertensive exposure, the cohort skewed to the younger-old (60-77.5 years) with a male majority. CCBs were the most commonly used class overall, followed by ARBs and BBs, with ACEIs least frequent (see Tables 2-7). These patterns are consistent with high antihypertensive exposure in late life and underscore the importance of considering dose burden and regimen complexity, not just class labels, when assessing fall risk (Lawson et al., 2018; Liu et al., 2023). While the estimate fell across profile variables, it showed that the incidence patterns were not uniform. Falls concentrated among older age, lower BMI, higher dose, ≥2 classes, and acute treatment strata (see Table 8). The BMI gradient is clinically salient; as a pragmatic proxy for frailty/malnutrition, lower BMI aligned with higher fall incidence, mirroring reports that frailty states are tied to injurious falls and other adverse outcomes in hypertensive older adults (Hu et al., 2021). These descriptive gradients foreshadowed the adjusted effects also seen within the proposed model.

Visually, Figure 1 shows the comparative bar chart, which summarizes within-stratum fall incidence and visually reinforces the study's core signals. Falls were more frequent among the older subgroup (77.60-95 years: 66.20%) than the younger-old (60-77.50 years: 43.10%), consistent with age-related declines in physiologic reserve. A clear BMI gradient was observed, with higher falls in the lower-BMI stratum (56.80%) than the higher-BMI stratum (43.10%), aligning with frailty/malnutrition as pragmatic risk proxies. Medication exposure patterns showed the largest separations: fall incidence increased sharply at higher total dosage (71.90% at 50-63 mg as compared with 25.0% at

0.45-49.90 mg), under multi-class regimens (86.30% for ≥2 classes versus 25.50% for a single class), and during the acute treatment window (77.20% acute versus 31.80% long-term). These descriptive contrasts anticipate and support the multivariable findings, highlighting dose burden, regimen complexity, and timing (initiation/intensification) as dominant, medication-defined contexts of risk. Clinically, the pattern points to time-bound, targeted prevention, such as assisted first ambulation and orthostatic monitoring during acute changes, closer rounding for multi-class or higher-dose regimens, and nutrition/frailty-informed safeguards for low-BMI patients, thereby concentrating resources where risk is most pronounced.

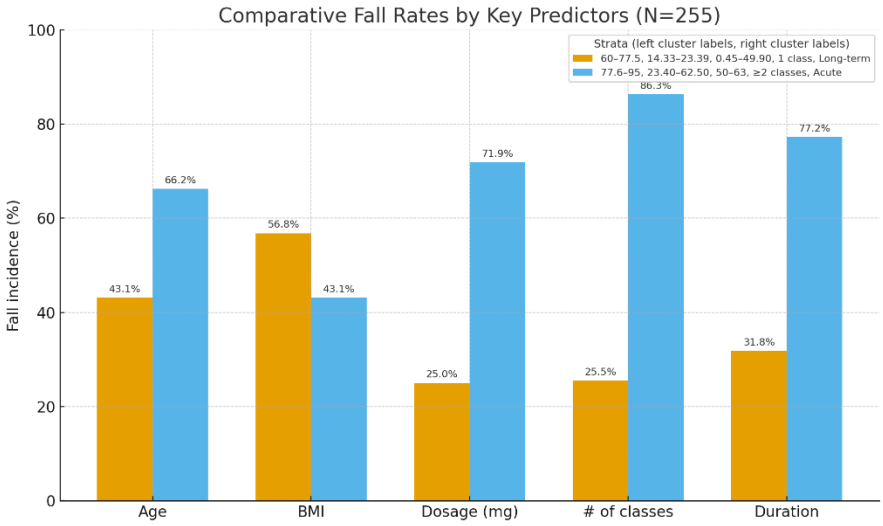

Fig. 1: Comparative fall incidence by key predictors (N = 255).

Notes. Bars display the within-stratum percentage of inpatients with a documented fall: Age (60-77.50 years old as compared to 77.60-95 years old), BMI (14.33-23.39 versus 23.40-62.50 kg/m²), medication dosage (0.45-49.90 versus 50-63 mg), number of antihypertensive classes (1 vs. ≥2), and duration of therapy (long-term vs. acute). Percentages are computed from Table 8 cell counts.

For the bivariate associations between falls and each predictor, results confirmed that advanced age, lower BMI, higher dose, polyclass regimens, and acute status as significant correlates (with Cramér's V ranging from small to large) (Cohen, 1988). Gender, height, and weight were not associated with falls, a pattern consistent with reviews that emphasize physiological reserve/frailty and exposure dynamics over simple anthropometrics (Kahlaee et al., 2018; Ribeiro et al., 2018). These findings justify the predictor set, which was later carried forward into multivariable modeling.

Lastly, multivariate logistic regression showed that the adjusted results reaffirmed the dual pathway to risk: (*a*) intrinsic vulnerability - older age (aOR≈1.04/year) and lower BMI (aOR≈0.90/unit) and (*b*) exposure intensity and timing - dose (aOR≈1.005/mg), ≥2 classes (aOR≈10), and acute phase (aOR≈3). This synthesis helps reconcile conflicting literature: null findings often stem from binary, time-insensitive exposure measures, whereas risks become evident with dose- and time-resolved definitions (Kahlaee et al., 2018; Shimbo et al., 2016). These findings would provide some clinical implications. For instance, screening and huddles to embed the number of classes, current dose, and recent changes into shift-start huddles. Acute-window bundle (24 to 48 hours) for assisted first ambulation post-change; orthostatic BP/HR; hydration prompt; toileting schedule; bed-exit alerting for select patients. Regimen review for polyclass and high-dose cases, consider staggering administration times, deprescribing, or class substitution when appropriate.

In sum, falls prolong hospital stay and degrade quality metrics. The current medication-aware model suggests specific, auditable process indicators: (1) time to first assisted ambulation after dose change, (2) completion rate for orthostatic vital checks within 24 hours, and (3) fall rate within 72 hours of antihypertensive intensification. Such measures connect risk prediction to nursing quality improvement and policy.

6. Conclusion

In this multi-hospital cohort of older inpatients receiving antihypertensives, falls clustered in predictable, medication-defined contexts; particularly during acute initiation or intensification, at higher total dose, under multi-class regimens, and among patients with lower physiologic reserve (advanced age, lower BMI). A parsimonious five-variable model (age, BMI, dose, number of classes, acute versus long-term) explained a substantial share of variance and yielded clear, time-bound triggers for intensified nursing surveillance and mobility support. By moving beyond crude "any use" exposure to dose-timing-complexity, the findings reconcile prior mixed evidence and translate cleanly into theory-grounded practice pathways, such as Orem (compensatory systems for transient self-care deficits), Roy (bundled responses to short-term adaptation lags), and Pender (micro-education to sustain preventive behaviors).

Clinical and systems implications. The model is suitable for bedside decision support and Electronic Health Record (HER) integration: banner alerts during the acute window after medication changes; shift-huddle tiles flagging assisted first ambulation within 24 to 48 hours; and order-set nudges for orthostatic vitals, hydration prompts, toileting schedules, and short-term bed-exit alerts in high-risk patients. Pharmacy-nursing collaboration can focus on regimen complexity and dosing burden, including staggering of classes, cautious titration, and deprescribing where appropriate, with special attention to low-BMI/frailty profiles.

Validation and generalizability. To enhance clinical credibility, internal validation with bootstrap optimism correction (discrimination and calibration) and decision-curve analysis was undertaken, followed by temporal validation on later-year admissions and external validation in an additional province with comparable EMR/AERS infrastructure; recalibration was applied as needed. These steps support performance stability and clinical utility, while acknowledging that site-specific recalibration is prudent before broader deployment.

Limitations. As a secondary analysis of routine EMR/AERS data from tertiary hospitals in a single city, generalizability to community or rural settings may be limited. Residual confounding from non-antihypertensive fall-risk-increasing drugs and multimorbidity is possible

given variable coding across sites. Measurement error in routine documentation and variability in fall reporting may affect precision. These constraints reflect real-world data capture and underscore the need for enriched covariate collection in future work.
Future directions. Priority next steps include (1) multi-site prospective studies that capture standardized frailty indices, orthostatic measures, and comprehensive FRID exposure; (2) pragmatic EHR implementation trials that link risk flags to auditable process indicators, such as assisted first ambulation within 24 hours of intensification, completion of orthostatic vitals, and 72-hour post-change fall rates; and (3) medication-strategy studies comparing titration speed, class staggering, and deprescribing algorithms in frail or low-BMI subgroups. Together, these advances can sharpen medication-aware fall prevention, concentrate resources where risk is highest, and strengthen nursing quality and patient safety.

Declaration of Generative AI and AI-assisted Technology Use in the Writing Process - The authors used ChatGPT and Wordtune only to enhance the language and readability of this work. The authors also thoroughly reviewed and refined the content to ensure accuracy, and assume full responsibility for the final published version.

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