



Development of a Mortality Prediction Score for Patients With Hip Fractures

Nutturn Daraphongsataporn, MD, Krairoek Waiwattana, MD, Worapong Sucharitpongpan, MD

Department of Orthopedics, Nan Hospital, Nan, Thailand

Purpose: This study developed and validated a context-specific Hip Fracture Mortality Score (HFMS) to predict 1-year mortality in Thai patients.

Methods: A retrospective cohort analysis evaluated consecutive hip fracture admissions at Nan Hospital (January 2019–December 2023), including 1,263 patients aged ≥ 60 years. Twenty-four candidate predictors were analyzed using univariate logistic regression; variables with $p < 0.20$ entered multivariate analysis. Beta coefficients were transformed into point values (rounded to the nearest 0.5) for clinical implementation.

Results: The overall 1-year mortality rate was 20.3%. Five independent predictors were identified: end-stage renal disease (adjusted odds ratio [aOR] 4.64, 95% confidence interval [CI] 2.097–10.263; 4 points), non-operative management (aOR 2.64, 95% CI 1.667–4.192; 2.5 points), anemia (aOR 2.02, 95% CI 1.451–2.807; 2 points), male sex (aOR 1.80, 95% CI 1.289–2.504; 1.5 points), and walking with aids (aOR 1.43, 95% CI 1.049–1.941; 1 point). The HFMS showed moderate discrimination (area under the curve [AUC] 0.701, 95% CI 0.666–0.737; optimism-corrected AUC 0.700 on bootstrap validation). A 2.5-point threshold (Youden's index: 0.296) yielded a sensitivity of 56.3%, specificity of 73.4%, positive predictive value of 35.0%, and negative predictive value (NPV) of 86.8%. Low-risk patients (< 2.5 points) had mortality rates of 7.97–20% versus 27.84–53.85% in high-risk patients (≥ 2.5 points).

Conclusions: The HFMS is a practical prognostic tool using five ascertainable parameters, avoiding complex algorithms. It addresses the limitations of Western-derived scoring systems in resource-constrained Thai healthcare settings. Despite moderate sensitivity, a high NPV effectively identifies low-risk patients. External validation and prospective evaluation warrant further investigation.

Keywords: Hip fracture, mortality prediction, prognostic scoring system, fragility hip fracture, risk-stratification

Hip fractures represent a major global public health challenge; the World Health Organization projects that their incidence will increase from 1.66 million cases in 1990 to 6.26 mil-

lion by 2050⁽¹⁾. In Thailand, this burden intensifies as the nation transitions into a super-aged society. Projections indicate that by 2040, nearly one in three Thai citizens (31.37% of the population) will be elderly⁽²⁾. The annual incidence of osteoporotic hip fractures has risen by 2%, with rates of 135.9 and 367.9 per 100,000 people in males and females, respectively⁽³⁾. In Nan Province specifically, incidence increased from 211.6 per 100,000 in 2015 to 238.5 per 100,000 in 2017. Females experienced rates 2.5 times higher than those of males and 87.2% of

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Correspondence to: Nutturn Daraphongsataporn, MD
Department of Orthopedics, Nan Hospital, Nan,
Thailand

E-mail: nutturn.d@nanhospital.go.th

fractures occurring at home⁽⁴⁾. The economic impact is substantial: annual hospitalization costs for hip fractures surged from \$17.3 million in 2013 to \$42.8 million in 2022—a 2.5-fold increase ($p < 0.001$)⁽⁵⁾. Despite advances in care, 1-year mortality remains alarmingly high at 10.8–23.8%⁽⁶⁾. Nan Province reports a 19% 1-year mortality rate and a risk of death 6.21 times higher than that of the general population⁽⁷⁾.

A systematic review identified 12 clinical parameters associated with hip fracture mortality: age, sex, American Society of Anesthesiologists score, cognitive status, dementia, pre-fracture mobility, activities of daily living, comorbidity burden, diabetes, cancer, cardiovascular disease, and facility residence⁽⁸⁾. Several prediction systems have been developed, including the Nottingham Hip Fracture Score (NHFS) from the United Kingdom⁽⁹⁾ and the Physiological and Operative Severity Score for the Enumeration of Mortality and Morbidity⁽¹⁰⁾. Recently, Thai machine learning models achieved superior discriminatory performance with area under the curve (AUC) values ranging from 0.81 to 0.99 for 1-year mortality prediction at tertiary centers⁽¹¹⁾. However, practical limitations constrain the widespread implementation of Western-derived scores and complex algorithms in diverse Thai healthcare settings.

Existing tools have several limitations in Thai provincial healthcare. Western models may have limited generalizability because of population differences in genetics, lifestyle, and comorbidity profiles. Some systems require comprehensive cognitive assessments or extensive laboratory data, which are unavailable in community hospitals. Machine learning models, while achieving superior discrimination, require computational infrastructure and lack clinical transparency, which limits their bedside applicability. Furthermore, existing tools fail to account for Thai-specific factors, including extended family care systems, village health volunteer networks, and sociocultural differences in health-seeking behaviors.

The development of a simple and clinically interpretable scoring system using readily available admission variables may enhance its practical utility in all Thai healthcare settings. Such a tool

would enable rapid bedside risk stratification, facilitate timely clinical decision-making, guide risk-stratified post-discharge care, including village health volunteer home visits, and optimize limited healthcare resources. Early identification of patients at high risk is crucial for appropriate treatment planning and, ultimately, for reducing hip fracture mortality in the aging population of Thailand.

To the best of our knowledge, no prior study has developed a simple point-based scoring tool specifically calibrated for provincial Thai hip fracture populations, and the present study addresses this gap directly.

This study aimed to develop a Hip Fracture Mortality Score (HFMS) to predict 1-year mortality in patients with hip fractures in Thailand, providing clinicians and healthcare professionals with the following tools: (1) identify patients at high risk from initial admission, (2) plan appropriate, risk-stratified treatment and follow-up care, (3) communicate prognosis effectively with patients and families, and (4) allocate medical resources efficiently. The development of the HFMS will improve risk stratification and clinical decision-making for patients with hip fractures in Thailand, ultimately leading to improved treatment outcomes, reduced mortality, and optimal healthcare resource utilization.

METHODS

This retrospective cohort study was conducted at Nan Hospital, Nan Province, Thailand, between January 1, 2019, and December 31, 2023. All patients admitted with hip fractures were screened for inclusion. The inclusion criteria included patients aged 60 years and older with radiologically confirmed hip fractures diagnosed as femoral neck, intertrochanteric, or subtrochanteric fractures (International Classification of Diseases, 10th Revision: S72.0–S72.2), including both intra-capsular and extracapsular fractures. Patients who underwent non-operative management were also included in the analysis. The exclusion criteria included pathological fractures, high-energy trauma fractures, and loss to follow-up. The final sample consisted of 1,263 patients.

Based on a systematic literature review and feasibility considerations for data collection in Thai hospitals, 24 predictor variables were selected for model development; demographic and baseline characteristics included age categorized as 60–64, 65–69, 70–74, 75–79, 80–84, 85–89, and ≥ 90 years^(7,8,12,13); sex^(8,12-15); and body mass index (BMI) categorized as <21 kg/m² versus ≥ 21 kg/m²⁽⁷⁾. Clinical factors collected included fall history⁽⁷⁾, caregiver presence^(8,12), time to hospital presentation categorized as <24 h versus ≥ 24 h⁽⁷⁾, length of stay <5 days versus ≥ 5 days⁽¹⁶⁾, fracture type classified as intracapsular versus extracapsular^(8,13), treatment modality as operative versus non-operative^(8,13), pre-fracture mobility categorized as independent walking, walking with aids, or wheelchair/bedridden^(7,8), and history of fragility fracture⁽⁷⁾. Comorbidities and complications assessed at admission included anemia (defined as hemoglobin <10 g/dL in females and <12 g/dL in males)⁽¹⁴⁾, electrolyte imbalance⁽⁷⁾, diabetes mellitus^(7,8), hypertension⁽⁷⁾, chronic obstructive pulmonary disease⁽¹²⁾, cardiovascular disease^(8,12,14), chronic kidney disease (defined as estimated glomerular filtration rate [eGFR] <60 mL/min/1.73 m²)⁽¹²⁾, end-stage renal disease (ESRD; defined as eGFR <15 mL/min/1.73 m²)⁽⁷⁾, dementia^(8,12), delirium at admission⁽¹²⁾, urinary tract infection⁽⁷⁾, pneumonia^(7,14), and sepsis⁽⁷⁾.

The required sample size for developing the prediction model was assessed using the criteria described by Riley et al. (pmsampsize). Assuming an outcome proportion of 20.3% and a Cox–Snell R^2 of 0.085 for the final five-parameter model, the minimum sample size required to ensure a uniform shrinkage factor ≥ 0.9 , an absolute difference between apparent and adjusted $R^2 \leq 0.05$, and precise estimation of overall risk was 507 patients (approximately 103 events). The available cohort of 1,263 patients with 256 events (events-per-parameter ≈ 51 for the final model) therefore exceeded the minimum requirement.

Data were extracted from the hospital's electronic medical record system (Hospital Information System) and paper-based records by two trained research nurses using a standardized data collection form developed according to the

TRIPOD+AI (2024) reporting guidelines for clinical prediction models. Quality control measures included complete data verification by the principal investigator and assessment of inter-rater reliability using Cohen's kappa ($\kappa = 0.85$). Outliers and missing data were verified against the original medical records, and mortality data were confirmed through civil registration systems and hospital mortality databases.

Statistical Analysis

All analyses were performed using SPSS Statistics version 26.0 (IBM Corp., Armonk, NY, USA). Statistical significance was defined as a two-tailed p-value <0.05 . Missing data (affecting $<5\%$ of the records) were addressed using listwise deletion.

The HFMS was developed using a structured, three-step statistical approach to identify predictors of 1-year mortality in patients with hip fractures and to construct a clinically applicable scoring system. First, univariate logistic regression analyses were performed to examine the association between each candidate variable and 1-year mortality. To avoid prematurely excluding potentially relevant factors, variables with a p-value <0.20 were retained. Second, all selected variables were simultaneously entered into a multivariate logistic regression model using the entry method. Variable selection for the final model was based on statistical significance (p-value <0.05). Third, to facilitate bedside applicability, regression coefficients (β) from the final multivariate model were transformed into point values. Each coefficient was divided by the smallest coefficient in the model and rounded to the nearest 0.5 to standardize the relative contribution of each predictor.

Internal validation of HFMS was performed by applying the derived equation to the study cohort. Model discrimination was assessed by plotting receiver operating characteristic (ROC) curves and calculating the AUC. The optimal cutoff score was determined using Youden's index. Additionally, the predictive performance of the HFMS was evaluated at multiple time points using sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV).

To address potential optimism when evaluating the model in its derivation cohort, internal validation was performed using bootstrap resampling (500 resamples), following Harrell's method. The optimism-corrected AUC and uniform shrinkage factor were calculated, and the shrinkage factor was applied to the regression coefficients. The model calibration was assessed using a calibration plot with a calibration intercept (calibration-in-the-large) and slope. Clinical utility was evaluated using decision curve (net benefit) analysis across a range of threshold probabilities. In addition, a sensitivity analysis was performed by excluding non-operative management, given its potential for confounding by indication.

Ethical Considerations

This study received approval from the Nan Hospital Research Ethics Committee (Nan Hospital REC No. 043/2025). Informed consent was waived due to the retrospective nature of the study using de-identified data. Data management complied with the Personal Data Protection Act B.E. 2562 (2019).

RESULTS

The primary outcome was all-cause mortality within 1 year of the hip fracture. Mortality status was verified using civil registration systems, hospital mortality databases, and telephone follow-ups. Of the 1,263 included patients, 345 were male and 918 were female. A total of 256 patients (20.3%) died within 1 year. First, univariate logistic regression analysis was performed to identify variables associated with 1-

year mortality. Eighteen variables met the selection criteria in univariate logistic regression, including age 85–89 years ($p = 0.149$), and ≥ 90 years ($p = 0.005$), male sex ($p < 0.001$), BMI $< 21 \text{ kg/m}^2$ ($p = 0.027$), time to hospital presentation $\geq 24 \text{ h}$ ($p = 0.125$), length of stay ≥ 5 days ($p = 0.004$), non-operative treatment ($p < 0.001$), pre-fracture mobility categorized as walking with aids or wheelchair/bedridden ($p < 0.001$), anemia, defined as hemoglobin $< 10 \text{ g/dL}$ in females and $< 12 \text{ g/dL}$ in males ($p < 0.001$), electrolyte imbalance ($p = 0.033$), chronic obstructive pulmonary disease ($p = 0.177$), cardiovascular disease ($p = 0.010$), chronic kidney disease, defined as eGFR $< 60 \text{ mL/min/1.73 m}^2$ ($p < 0.001$), ESRD, defined as eGFR $< 15 \text{ mL/min/1.73 m}^2$ ($p < 0.001$), dementia ($p = 0.094$), delirium at admission ($p < 0.001$), urinary tract infection ($p = 0.176$), pneumonia ($p = 0.001$), and sepsis ($p < 0.001$) (Table 1).

Second, all 18 variables were subjected to multivariate logistic regression analysis using the enter method. Five significant variables were retained in the final model: male sex ($p = 0.001$), non-operative treatment ($p < 0.001$), walking with aids ($p = 0.024$), anemia ($p < 0.001$), and ESRD ($p < 0.001$) (Table 2). Third, to facilitate practical application, the regression coefficients (β) from the multivariate model were converted into point values. Each coefficient was divided by the smallest absolute β -value (0.355) and rounded to the nearest 0.5 for computational convenience. The final formula for the HFMS is calculated as follows:
 $\text{HFMS} = 1.5 \text{ (Male)} + 2.5 \text{ (Non-operative)} + 1 \text{ (Walking with aids)} + 2 \text{ (Anemia)} + 4 \text{ (ESRD)}$

Table 1 Univariate logistic regression analysis.

Risk factors	Number of deaths within 1 year, N (%)	Odds ratio (OR)	95% CI	p-value*
Age group (year)				
60–64	6 (13%)	Reference		
65–69	7 (8.6%)	0.631	0.198–2.004	0.435
70–74	21 (15.0%)	1.176	0.444–3.120	0.744
75–79	36 (16.5%)	1.319	0.521–3.341	0.56
80–84	56 (18.9%)	1.556	0.629–3.849	0.339
85–89	72 (22.5%)	1.935	0.789–4.748	0.149

Risk factors	Number of deaths within 1 year, N (%)	Odds ratio (OR)	95% CI	p-value*
≥90	58 (35.8%)	3.718	1.487–9.294	0.005
Male	107 (30.9%)	2.308	1.731–3.077	<0.001
BMI <21 kg/m ²	102 (17.6%)	0.730	0.552–0.965	0.027
History of fall	39 (20.9%)	1.043	0.711–1.530	0.829
Caregiver	1 (25%)	1.312	0.136–12.670	0.814
Time to admit ≥24 h	62 (23.7%)	1.290	0.932–1.785	0.125
Length of stay ≥5 days	153 (23.4%)	1.506	1.140–1.990	0.004
Diagnosis: extracapsular fracture	204 (21.1%)	1.241	0.886–1.738	0.209
Non-operative treatment	45(40.9%)	3.175	2.115–4.765	<0.001
Walking with aids	153 (25.4%)	1.839	1.391–2.430	<0.001
Anemia	96 (30.7%)	2.184	1.628–2.932	<0.001
Electrolyte imbalance	44 (26.5%)	1.506	1.034–2.192	0.033
DM	45 (21.6%)	1.104	0.768–1.587	0.592
HT	165 (20.5%)	1.049	0.788–1.396	0.745
COPD	32 (24.8%)	1.34	0.876–2.051	0.177
Cardiovascular disease	22 (32.8%)	2.01	1.184–3.413	0.01
CKD	59 (29.5%)	1.839	1.308–2.587	<0.001
ESRD	16 (50%)	4.129	2.036–8.375	<0.001
Dementia	30 (26.32%)	1.459	0.938–2.268	0.094
History of hip fragility fracture	15 (15.5%)	0.702	0.398–1.239	0.223
Delirium	48 (32.4%)	2.093	1.438–3.048	<0.001
UTI	38 (24.4%)	1.313	0.885–1.948	0.176
Pneumonia	19 (38.8%)	2.611	1.444–4.719	0.001
Sepsis	15 (48.4%)	3.855	1.880–7.907	<0.001

Variables with a p-value < 0.2 in the univariate analysis were included in the multiple logistic regression model.

Abbreviations: BMI, body mass index; CI, confidence interval; CKD, chronic kidney disease; COPD, chronic obstructive pulmonary disease; DM, diabetes mellitus; ESRD, end-stage renal disease; HT, hypertension; UTI, urinary tract infection.

*Statistical significance was set at $p < 0.05$.

Multivariate logistic regression analysis identified five independent predictors of 1-year mortality: ESRD (adjusted odds ratio [aOR] 4.64, 95% confidence interval [CI] 2.097–10.263; weighted score 4 points), non-operative management (aOR 2.64, 95% CI 1.667–4.192; weighted score 2.5 points), anemia at admission (aOR 2.02, 95% CI 1.451–2.807; weighted score 2 points), male sex (aOR 1.80, 95% CI 1.289–2.504; weighted score 1.5 points), and walking with aids (aOR 1.43, 95% CI 1.049–1.941; weighted score 1 point) (Tables 2 and 3). The resulting HFMS score ranged from 0 to 11 points, with higher scores corresponding to an increased risk of 1-year mortality following a hip fracture.

To enhance clinical applicability, the scoring system was designed to prioritize simplicity and feasibility. Integer weights derived from regression coefficients enable rapid bedside calculations without requiring specialized tools, thereby facilitating implementation in resource-limited settings.

Internal Validation

Model performance was evaluated through internal validation. The discriminatory ability, as assessed by the area under the ROC curve (AUC), was 0.701 (95% CI 0.666–0.737; $p < 0.001$). This level of discrimination represents moderate-to-good predictive capability, which is considered acceptable for clinical use, particularly given the ease of

calculation without relying on advanced laboratory investigations. For bootstrap internal validation (500 resamples), the optimism-corrected AUC was 0.700 (apparent AUC was 0.705), indicating

minimal optimism, and the uniform shrinkage factor was 0.96, indicating that the model coefficients required minimal shrinkage. The ROC curve is shown in Fig. 1.

Table 2 Multivariate logistic regression analysis.

Risk factors	Coefficient	Adjusted odds ratio (aOR)	95% CI	p-value*
Age group (year)		Reference		
60–64				
65–69	-0.583	0.558	0.159–1.954	0.362
70–74	0.185	1.203	0.407–3.555	0.738
75–79	0.103	1.108	0.391–3.141	0.847
80–84	0.226	1.254	0.450–3.493	0.665
85–89	0.402	1.494	0.538–4.151	0.441
≥90	1.015	2.759	0.963–7.909	0.059
Male	0.586	1.797	1.289–2.504	0.001
BMI <21 kg/m ²	-0.201	0.818	0.601–1.113	0.201
Time to admit ≥24	0.169	1.184	0.831–1.686	0.351
Length of stay ≥5 days	0.221	1.248	0.901–1.727	0.183
Non-operative treatment	0.972	2.644	1.667–4.192	<0.001
Walking with aids	0.355	1.427	1.049–1.941	0.024
Anemia	0.702	2.018	1.451–2.807	<0.001
Electrolyte imbalance	0.212	1.236	0.812–1.881	0.323
COPD	-0.026	0.975	0.604–1.574	0.916
Cardiovascular disease	0.473	1.605	0.898–2.867	0.110
CKD	0.351	1.421	0.972–2.077	0.070
ESRD	1.534	4.639	2.097–10.263	<0.001
Dementia	0.332	1.394	0.858–2.267	0.180
Delirium	0.297	1.346	0.870–2.082	0.182
UTI	0.061	1.063	0.680–1.663	0.788
Pneumonia	0.260	1.297	0.656–2.567	0.455
Sepsis	0.686	1.985	0.849–4.640	0.114

Abbreviations: BMI, body mass index; CI, confidence interval; CKD, chronic kidney disease; COPD, chronic obstructive pulmonary disease; ESRD, end-stage renal disease; UTI, urinary tract infection.

*Statistical significance was set at $p < 0.05$.

Table 3 Risk factors and risk scores.

Risk factors	Coefficient	Adjusted odds ratio (aOR)	Score
Male	0.586	1.65	1.5
Non-operative treatment	0.972	2.74	2.5
Walking with aids	0.355	1.00	1
Anemia	0.702	1.98	2
ESRD	1.534	4.32	4
Total			11

Abbreviation: ESRD, end-stage renal disease.

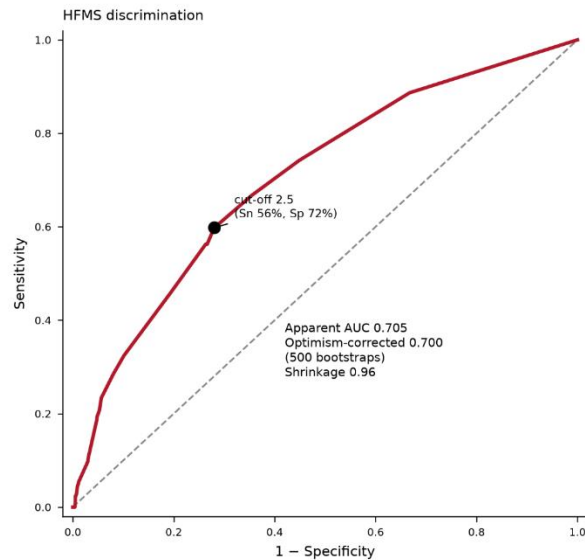


Fig. 1 Receiver operating characteristic (ROC) curve and area under the curve (AUC) for the HFMS. HFMS, Hip Fracture Mortality Score.

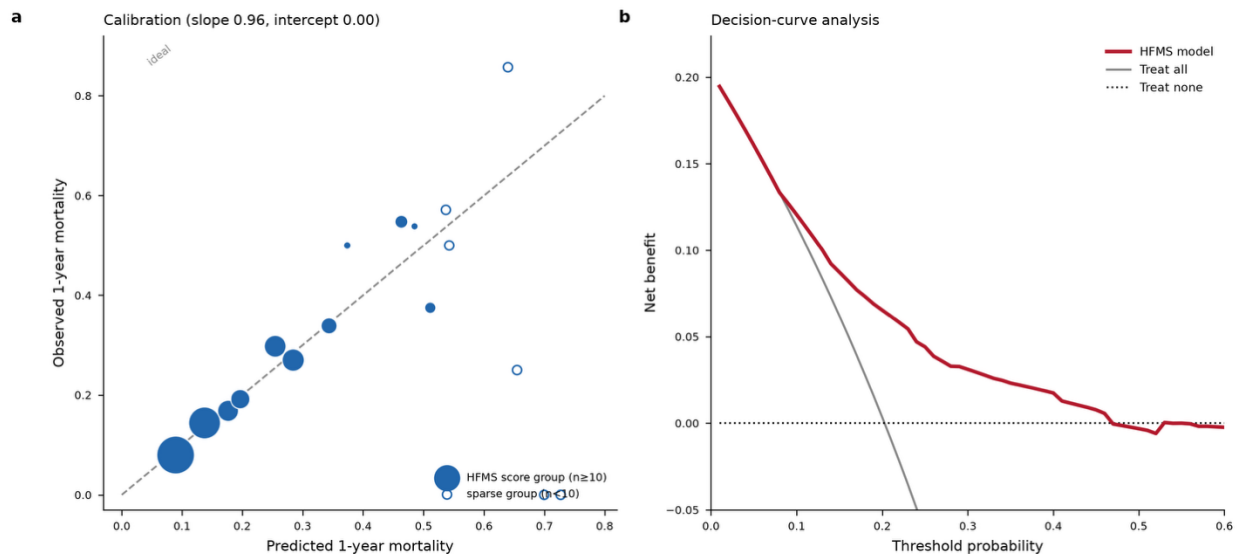


Fig. 2 Internal validation of the Hip Fracture Mortality Score (HFMS): (a) calibration plot and (b) decision-curve analysis.

Calibration was satisfactory, with a slope of 0.96 and an intercept close to zero; the calibration plot is shown in Fig. 2.

Decision-curve analysis demonstrated a positive net benefit for the HFMS across the clinically relevant range of threshold probabilities, exceeding both the treat-all and treat-none strategies. In a sensitivity analysis excluding non-operative management, the remaining four

predictors retained statistical significance, and the direction of their associations was unchanged, with an AUC of 0.674.

The optimal cutoff score was determined using Youden's index. A threshold of 2.5 points yielded the highest Youden's index (0.296), corresponding to a sensitivity of 56.3% and specificity of 73.4% (Table 4). Although the sensitivity was moderate, the relatively high specificity reduced

the false-positive classifications among lower-risk patients. At this threshold, the PPV was 35.0% and the NPV was 86.8%. The high NPV is clinically

relevant, providing reassurance that patients with scores <2.5 have a high probability of survival. The overall predictive accuracy of the model was 69.9%.

Table 4 Death score from Youden's index.

Death score	Sensitivity (%)	Specificity (%)	Youden index
0.50	88.7	33.3	0.219
1.50	74.2	55.1	0.293
2.50	56.3	73.4	0.296*
3.50	28.5	91.7	0.202
4.50	20.7	94.6	0.153
5.50	5.9	98.6	0.045
6.50	3.9	99.1	0.030
7.50	1.2	99.7	0.009

Cutoff death score = 2.5; Sensitivity = 56.3%; Specificity = 73.4%.

*Optimal cutoff point determined by Youden's index.

Mortality distribution according to the HFMS scores revealed two distinct risk-stratified groups. Patients in the low-risk group (score <2.5) demonstrated mortality rates ranging from 7.97% to 20.0%, whereas those in the high-risk group (score ≥ 2.5) exhibited mortality rates between 27.84% and 53.85%. This marked difference in mortality across the groups highlights the clinical utility of HFMS in guiding risk-stratified management. Furthermore, a clear linear relationship was observed between the HFMS score and mortality risk; each 1-point increase in the score was associated with an approximately 6–8% increase in mortality. This dose–response relationship reinforces the

robustness of the scoring system and supports its use for detailed prognostic stratification.

Beyond 1-year mortality prediction, the HFMS also demonstrated predictive validity across multiple time horizons. The sensitivity declined from 60.3% at 90 days to 56.3% at 1 year, whereas the specificity improved from 70.2% to 73.4% over the same interval. The PPV increased substantially from 17.0% at 90 days to 35.0% at 1 year, while the NPV remained consistently high across all time points (86.8–94.6%) (Table 5). These findings highlight the dynamic predictive characteristics of the HFMS and its potential applications in both short- and long-term prognostication.

Table 5 Performance of the HFMS in predicting mortality at multiple time points.

Parameter	90 days	180 days	1 year
Sensitivity (%)	60.3	59.2	56.3
Specificity (%)	70.2	71.8	73.4
PPV (%)	17.0	25.7	35.0
NPV (%)	94.6	91.4	86.8
Accuracy (%)	69.3	70.0	69.9

Abbreviations: HFMS, Hip Fracture Mortality Score; NPV, negative predictive value; PPV, positive predictive value.

DISCUSSION

This study developed the HFMS, a simple five-variable prediction model for 1-year all-cause mortality in elderly Thai patients with hip frac-

tures. The HFMS incorporated readily obtainable admission variables: ESRD, non-operative treatment, anemia, male sex, and walking with aids, and demonstrated moderate discriminatory perfor-

mance (AUC 0.701). The model exhibited a high NPV (86.8%), effectively identifying patients at low risk. Furthermore, the PPV increased substantially over time (from 17.0% at 90 days to 35.0% at 1 year), which enhances confidence in long-term high-risk identification.

Among the identified predictors, ESRD emerged as the strongest mortality determinant (aOR 4.64), which likely reflects renal osteodystrophy, cardiovascular comorbidities, and limited physiological reserves⁽⁷⁾. Non-operative treatment (aOR 2.64) independently predicted mortality, often as an indicator of advanced frailty that precluded surgery and complications from prolonged immobilization, such as infection, thromboembolism, and functional decline^(8,13). Anemia at admission (aOR 2.02) served as a marker of poor physiological reserve, while male sex (aOR 1.80) and walking with aids (aOR 1.43) reflected a greater comorbidity burden and baseline functional impairment, respectively, which are all established prognostic factors in the hip fracture literature^(7,8,14).

The inclusion of non-operative treatment warrants caution. The decision to manage a hip fracture non-operatively is frequently driven by the treating clinician's assessment of frailty, comorbidity burden, and perceived unfit for surgery. Therefore, non-operative patients are triaged to that pathway because they are already considered to be at high risk. This represents confounding by indication; the variable is a marker of unfit rather than an independent causal determinant of mortality, and it is partly determined after admission. Consequently, this component of the score cannot be used to inform the operative versus non-operative decision itself, and when the score is applied at admission, before that decision is made, the availability and interpretation of this variable differ from those of the other four predictors. To quantify its influence, we performed a sensitivity analysis excluding non-operative treatment; the remaining four predictors retained significance, and the model's discrimination remained acceptable (AUC 0.674), which indicates that the score is robust to the removal of this variable.

The HFMS differs operationally from established tools such as the NHFS, which incorpo-

rates cognitive assessment, comorbidity counts, and institutional residence. Although it is comprehensive, it may have limited utility when cognitive testing is impractical or incomplete. In contrast, the HFMS relies exclusively on the five variables routinely available at admission to enable rapid bedside applications, particularly in resource-constrained settings. Although its discriminatory performance (AUC 0.701) is lower than that of some Thai machine learning models (AUC 0.81–0.99), it prioritizes clinical simplicity and interpretability to potentially facilitate broader implementation in routine practice^(8,11).

The HFMS is especially useful for guiding post-discharge home-visit programs and community-based care, addressing a critical gap in hip fracture management. Risk stratification enables targeted resource allocation across three clinically meaningful timeframes. During the first 90 days post-fracture, patients with an HFMS ≥ 2.5 (17.0% mortality risk) warrant intensive monitoring through early home visits by village health volunteers or community health workers who focus on wound assessment, medication adherence, fall prevention, and early complication detection. At 180 days, patients at high risk (26% mortality) require intermediate rehabilitation assessment, nutritional counseling, and care plan modifications based on functional recovery. A 1-year assessment (35% mortality in the high-risk group) guides long-term osteoporosis management, recurrent fall prevention, and comorbidity optimization.

Conversely, patients with an HFMS < 2.5 demonstrate a high survival probability (87–95% across timeframes), allowing reassurance and less intensive follow-up schedules, thereby optimizing limited community health resources. This risk-stratification approach aligns with emerging evidence from Nan Province, where village health volunteer home visits to elderly individuals at high risk markedly reduced primary hip fracture incidence. However, Fracture Liaison Service programs alone failed to reduce mortality, highlighting the necessity of integrated hospital-community care models^(4,7,17).

Practical implementation requires clear communication. Patients at high risk and their

families should understand the stepwise mortality risk (17% at 90 days, 26% at 180 days, and 35% at 1 year), facilitating informed decision-making and advance care planning. Furthermore, patients scoring ≥ 4 points, who face a nearly 50% 1-year mortality rate, warrant multidisciplinary care coordination, comprehensive geriatric assessment, and continuous family counseling. The HFMS may also serve as a quality metric for comparing outcomes between institutions and guiding resource allocation in Thailand's evolving universal healthcare system.

This study has several important limitations. Because this was a retrospective, single-center derivation study, external validation in diverse Thai populations is essential before widespread adoption. The moderate sensitivity (56.3%) indicated that the HFMS might not identify all patients at high risk of mortality, necessitating integration with comprehensive clinical judgment rather than standalone use. Potentially important variables, including serum albumin level, formal frailty assessment, and cognitive status, were incompletely captured, possibly limiting the model accuracy. Additionally, this study did not assess the functional outcomes or quality of life, which are important patient-centered endpoints beyond mortality. Although we now report bootstrap internal validation, calibration, and decision-curve analysis, the model still lacks external and prospective validation to demonstrate whether HFMS-guided care improves outcomes.

Future research should prioritize multicenter external validation across diverse Thai healthcare settings to establish generalizability. The development of a mobile application interface would enhance the accessibility for primary care personnel and village health volunteers, thereby facilitating real-world implementation. Prospective intervention trials should evaluate whether HFMS-guided risk-stratified care, including targeted home-visit programs, reduces mortality, improves functional outcomes, and optimizes healthcare resource utilization. Integration with existing primary prevention tools (e.g., FRAX) may enable comprehensive community-based fracture-prevention programs. Finally, model refinement incorpo-

rating additional biomarkers or frailty indices may improve the discriminatory performance while maintaining clinical simplicity.

CONCLUSION

The HFMS is a pragmatic and easily implementable tool for mortality risk stratification in elderly Thai patients with hip fractures. Its primary strengths lie in its simplicity and high NPV, making it particularly suitable for guiding risk-stratified community follow-up programs and optimizing limited healthcare resources in provincial settings. While external validation and prospective evaluation are necessary, the HFMS addresses a critical need for accessible prognostic tools in resource-constrained environments and may facilitate integrated hospital-community care models to reduce hip fracture mortality in Thailand's aging population.

CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest relevant to this article.

DECLARATION OF GENERATIVE AI IN SCIENTIFIC WRITING

During the preparation of this work, the authors used Claude, developed by Anthropic, for language editing and spelling corrections. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

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