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Unchana Sura-amonrattana
Mahidol University
Suparat Saetan
Mahidol University
Pornjuree Saepoo
Mahidol University
Varalak Srinonprasert
Mahidol University
Manatchanok Kunin
Mahidol University
Rungnapha Saeliw
Mahidol University
Laddawan Himkhun
Mahidol University
Kullathorn Thephamongkhol
Mahidol University
Sasima Tongsai
Mahidol University
Katewarang Lekpet
Mahidol University
Direk Tantigate
dtantigate@gmail.com

Mahidol University

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Predicting 7-Day Major Complications in Hip Fracture Surgery: A Prognostic Model and Temporal Validation

Authors: Unchana Sura-amonrattana, MD[1]; Suparat Saetan, MD[1]; Pornjuree Saepoo, MD[1]; Varalak Srinonprasert, MD[1]; Manatchanok Kunin, RN[2]; Rungnapha Saeliw, RN[2]; Laddawan Himkhun, RN[2]; Kullathorn Thephamongkhol, MD[3]; Sasima Tongsai, PhD[4]; Katewarang Lekpet, BSc[5]; Direk Tantigate, MD[6*]

Author Affiliations:

[1] Division of Geriatric Medicine, Department of Medicine, Faculty of Medicine Siriraj Hospital, Mahidol University, Bangkok, Thailand

[2] Department of Nursing, Faculty of Medicine Siriraj Hospital, Mahidol University, Bangkok, Thailand

[3] Division of Radiation Oncology, Department of Radiology, Faculty of Medicine Siriraj Hospital, Mahidol University, Bangkok, Thailand

[4] Research Department, Faculty of Medicine Siriraj Hospital, Mahidol University, Bangkok, Thailand

[5] Research Division, Dean's Office, Faculty of Medicine Siriraj Hospital, Mahidol University, Bangkok, Thailand

[6] Department of Orthopaedic Surgery, Faculty of Medicine Siriraj Hospital, Mahidol University, Bangkok, Thailand

Corresponding Author: Direk Tantigate, MD. Department of Orthopaedic Surgery, Faculty of Medicine Siriraj Hospital, Mahidol University, 2 Wanglang Rd, Bangkoknoi, Bangkok 10700, Thailand. Email: dtantigate@gmail.com

Abstract

Background: Major complications within the first week after hip fracture surgery are prevalent and clinically significant. Existing preoperative risk models primarily predict mortality or overall risk, rather than early postoperative morbidity. This study aimed to develop and temporally validate a prognostic model predicting major complications within the 7 days post-hip fracture surgery, utilizing routine comprehensive geriatric assessments and admission laboratory parameters.

Methods: This prognostic study developed a model using a cohort of consecutive patients aged 65 years or older admitted with fragility hip fractures to a university hospital in Bangkok, Thailand (September 2017–December 2020). Temporal validation utilized a subsequent cohort (January 2021–November 2022). All patients were managed within an orthogeriatric fast-track pathway. Nineteen pre-specified candidate predictors spanning comprehensive geriatric assessment domains and routine laboratory values were evaluated. The primary outcome was any major complication (myocardial infarction, heart failure, stroke or transient ischemic attack, venous thromboembolism, respiratory failure, shock, or death) within the 7 days post-surgery. Predictors were selected via least absolute shrinkage and selection operator (LASSO) regression, with optimism estimated through internal bootstrapping.

Results: Among 1020 derivation cohort patients (median [IQR] age, 82 [77–87] years; 77.5% female), 87 (8.5%) experienced major complications. Six predictors were retained: age, Clinical Frailty Scale, Charlson Comorbidity Index, serum albumin, serum sodium, and routine medication count. The model demonstrated an apparent C-statistic of 0.729 (95% CI, 0.671–0.785) and an optimism-corrected C-statistic of 0.712. A derived bedside score (range, 0–21) yielded a corrected

C-statistic of 0.707. Complication rates increased progressively across four risk categories from 1.2% to 18.8% (odds ratio per category increase, 2.42; 95% CI, 1.86–3.16). In temporal validation (427 patients; 40 events), the model maintained a C-statistic of 0.703 (95% CI, 0.614–0.790; calibration slope, 0.840). This discrimination significantly outperformed existing standard risk indices (all $p \leq 0.002$).

Conclusions: Integrating comprehensive geriatric assessment data with routine laboratory parameters provided more accurate risk stratification for early postoperative complications compared with conventional instruments. External validation is required prior to broad clinical implementation.

Keywords: Hip fracture, Prognostic model, Postoperative complications, Comprehensive geriatric assessment, Older adults

Introduction

Hip fracture represents one of the most frequent indications for acute orthopedic admission among older adults and is associated with substantial early morbidity and mortality.[1,2] Major complications occurring during the first postoperative week—such as cardiac events, stroke, venous thromboembolism, respiratory failure, and death—prolong hospital stays, impair functional recovery, and increase the likelihood of institutionalization.[3-5] Early identification of these risks at admission could guide the intensity of perioperative monitoring, facilitate targeted prophylaxis, and support shared decision-making with patients and their families.[5-7]

However, available bedside assessment tools were predominantly developed for alternative clinical end points. The American Society of Anesthesiologists (ASA) physical status classification assesses global anesthetic risk,[8] the Charlson Comorbidity Index (CCI) measures long-term mortality burden,[9] and the Clinical Frailty Scale (CFS) evaluates overall physiological reserve.[10,11] Furthermore, the Nottingham Hip Fracture Score (NHFS) and the Revised Cardiac Risk Index (RCRI) were specifically derived to predict 30-day mortality and perioperative cardiac events, respectively.[12-14] When these instruments are repurposed to predict early composite complications rather than mortality, their discriminatory capacity is generally modest.[15,16]

Comprehensive geriatric assessment (CGA) is routinely performed within orthogeriatric pathways, yielding critical data regarding frailty, cognition, comorbidity, nutritional status, and medication burden.[7,17] While these domains are theoretically linked to early surgical risk, they are rarely integrated into a predictive model specifically targeting early major complications. It remains unclear whether routinely collected CGA data can accurately predict these events and how such a model would compare with existing risk stratification tools. Therefore, this study aimed to

develop and internally validate a prediction model for major complications within 7 days after hip fracture surgery, employing a variable-selection and validation methodology designed to mitigate optimistic bias.

Methods

Study Design and Participants

This prognostic study evaluated consecutive patients enrolled in the Siriraj Acute Geriatric Hip Fracture Fast-Track program at Siriraj Hospital, a university-affiliated tertiary care center in Bangkok, Thailand, from September 2017 to November 2022. Patients were eligible if they were aged 60 years or older, were admitted with a fragility hip fracture, and underwent surgery within the integrated orthogeriatric pathway. Of 1022 consecutively enrolled patients, 2 were excluded before analysis: 1 with decompensated heart failure precluding surgery and 1 who did not undergo surgery and represented a duplicate registry entry. The final analytic cohort comprised 1020 patients. The Siriraj Institutional Review Board approved this study (COA Si175/2025) and waived the requirement for informed consent because of the study design. Reporting adheres to the TRIPOD+AI guideline (eTable 1 in Supplement 1).[18]

Outcome

The primary outcome was any major complication occurring within 7 days after surgery, specified a priori as myocardial infarction, congestive heart failure, ischemic stroke or transient ischemic attack, deep vein thrombosis or pulmonary embolism, respiratory failure, shock or death. Complications were recorded by the orthogeriatric team using standardized, pre-specified case definitions applied to clinical documentation independently of predictor values and the prediction

model. To ensure diagnostic accuracy, all events were subsequently reviewed by a geriatric medicine fellow. Recorded event dates were utilized to confirm occurrence within the 7-day window.

Candidate Predictors

Nineteen candidate predictors were specified as a priori and restricted to information available at admission to ensure the resulting model could be applied preoperatively. Candidates encompassed CGA domains (age, sex, body mass index, cognitive status, ambulation status, CFS, mood status, CCI [calculated without the age component], serum albumin, number of routine medications, and Anticholinergic Cognitive Burden score) alongside admission laboratory values (hemoglobin, blood urea nitrogen, serum sodium, and the neutrophil-to-lymphocyte, platelet-to-lymphocyte, and lymphocyte-to-monocyte ratios).[9,10,19-22] Candidate variables had no missing values (eTable 2 in Supplement 1).

Model Development

Predictors were selected via least absolute shrinkage and selection operator (LASSO) logistic regression.[23] Continuous variables were standardized, and the penalty parameter was tuned via 10-fold cross-validation maximizing the cross-validated C statistic. Variables retained at the optimal penalty were entered into a multivariable logistic regression model without further pruning to prevent the instability and optimism associated with significance testing after penalized regression.[23,24]

To facilitate point-of-care use, retained predictors were categorized at pre-specified thresholds based on published literature and clinical convention: age (<75, 75-84 and ≥85 years),

frailty (CFS ≥5), comorbidity (CCI ≥3), hypoalbuminemia (albumin <3.5 g/dL), hyponatremia (sodium <135 mEq/L), and polypharmacy (≥5 routine medications).[10,19,25,26] A secondary logistic model was fitted to these categorical terms. Integer points were assigned by dividing each coefficient by the smallest retained coefficient and rounding to the nearest whole number.[27]

Statistical Analysis

Discrimination was quantified using the C statistic with 2000-replicate bootstrap 95% CIs. Calibration was assessed via calibration plots, calibration slope and intercept, maximum absolute calibration error, and the Brier score. Internal validation employed bootstrap optimism correction.[24] To accurately capture optimism attributable to variable selection, the entire model-building sequence (LASSO selection, model fitting, and point derivation) was repeated within each of the 250 bootstrap resamples. The required sample size was calculated using the criteria of Riley and colleagues for developing a clinical prediction model. Assuming an outcome prevalence of 8.5%, 6 predictor parameters, and a conservative anticipated Cox-Snell R2 of 0.054 (corresponding to the observed apparent model fit), the minimum sample size required to limit overfitting (targeting a global shrinkage factor of 0.9), to constrain the optimism in the apparent R2 to 0.05 or less, and to estimate the overall outcome risk with a margin of error of 0.05 or less was 972 patients (corresponding to 83 events). The available cohort of 1020 patients with 87 events exceeded this requirement and yielded 14.5 events per candidate parameter in the final model, consistent with established recommendations for prediction-model development.[28,29]

Discrimination was compared with 5 established instruments: the CCI, CFS, ASA classification, RCRI, and NHFS (reconstructed from recorded variables, excluding the unavailable institutional-residence item). Differences in C statistics were evaluated using a paired bootstrap

method (2000 replicates). Clinical utility was assessed via decision curve analysis across threshold probabilities of 2% to 35%. Continuous predictor linearity was confirmed using restricted cubic splines (all $p > 0.20$ for nonlinearity). Analyses were conducted in R, version 4.5, with 2-sided $p < 0.05$ indicating statistical significance.

Temporal external validation (TRIPOD type 2b) was performed by chronologically dividing the cohort. Patients admitted from September 2017 to December 2020 constituted the development sample, whereas those admitted from January 2021 to November 2022 formed the validation sample.

Results

Participants and Outcome

The cohort comprised 1020 patients (median [IQR] age, 82 [77-87] years; 790 [77.5%] female; 230 [22.5%] male), all with complete data for the 6 final predictors. Within 7 days of surgery, 87 patients (8.5%) developed a major complication, and 17 died. Compared with patients without complications, affected individuals were significantly older, frailer, and exhibited a higher comorbidity burden, increased polypharmacy, and lower serum sodium and albumin concentrations (Table 1).

Variable Selection and Final Model

LASSO regression retained 6 predictors at the cross-validation-optimal penalty: age, CFS, CCI, serum albumin, serum sodium, and the number of routine medications (cross-validated C statistic, 0.695). These variables spanned core CGA domains—demographics, frailty,

comorbidity, nutrition, and medication burden—along with a single metabolic parameter (eTable 3 in Supplement 1). Multivariable estimates demonstrated that age, comorbidity, and sodium remained independently associated with the outcome after adjustment (Table 2). For transparency, the full multivariable model including all 19 candidate predictors is provided in eTable 4 in Supplement 1; age, comorbidity, and sodium remained independently associated with the outcome in that model, and no strongly associated predictor was excluded by penalization.

Bedside Score

Categorization at pre-specified thresholds yielded a 7-term score ranging from 0 to 21 points (Table 2). The predicted probability was calculated as $1 / (1 + e^{-(-4.816 + 0.189 \times \text{total score})})$. The most substantial risk contributions were an age of 85 years or older, substantial comorbidity, and polypharmacy. The point assignment and predicted risk by score category are provided in eTable 5 and eTable 6 in Supplement 1. A nomogram representing the underlying continuous model is provided for transparency (eFigure 1 in Supplement 1); the integer bedside score is intended as the primary practical tool.

Discrimination, Calibration, and Risk Stratification

The continuous model achieved an apparent C statistic of 0.729 (95% CI, 0.671-0.785) and an optimism-corrected C statistic of 0.712. The corrected calibration slope was 0.904, and the corrected intercept was −0.380 (Figure 2A). The bedside score performed comparably (apparent C statistic, 0.729 [95% CI, 0.680-0.777]; optimism-corrected C statistic, 0.707) (Figure 2B). Detailed apparent and optimism-corrected performance metrics for both models are provided in eTable 7 in Supplement 1. Complications increased monotonically across 4 pre-specified risk

categories, ranging from 1.2% (2 of 165 patients) in the low-risk group to 18.8% (40 of 213 patients) in the very-high-risk group (odds ratio per category increase, 2.42; 95% CI, 1.86-3.16; p < 0.001) (Table 3). Discrimination was consistent across pre-specified subgroups defined by sex, age, operative type, and comorbidity burden (C statistics, 0.70-0.74; eTable 8 in Supplement 1).

Temporal Validation

In the temporal validation sample (n = 427; 40 events [9.4%]), the continuous model maintained a C statistic of 0.703 (95% CI, 0.614-0.790), with a calibration slope of 0.840, indicating preserved discrimination and acceptable recalibration. Development and validation performance is detailed in eTable 9, and baseline characteristics of the 2 samples are compared in eTable 10 in Supplement 1. The bedside score performed equivalently (C statistic, 0.715 [95% CI, 0.639-0.787]). In this validation cohort, a low-risk threshold of fewer than 8 points classified 21% of patients (88 of 427) as low risk, among whom only 1 major complication occurred, yielding a negative predictive value of 98.9%.

Comparison With Existing Instruments

The developed score demonstrated superior discrimination compared with all evaluated standalone comparators (Figure 1; Table 3): the CCI (difference, 0.071; p = 0.002), RCRI (difference, 0.097; p = 0.002), NHFS (difference, 0.120; p < 0.001), ASA classification (difference, 0.121; p < 0.001), and CFS (difference, 0.120; p < 0.001). Decision curve analysis indicated greater net benefit than treat-all or treat-none strategies across threshold probabilities of approximately 5% to 25% (Figure 2C).

Discussion

In this prognostic study of 1020 older adults undergoing hip fracture surgery, a predictive model incorporating 6 variables derived from routine preoperative CGA and laboratory testing demonstrated an optimism-corrected C statistic of 0.71 for predicting major complications within the first postoperative week. The model significantly outperformed 4 established instruments frequently utilized for risk stratification in this population. Because the retained predictors map directly onto standard CGA domains, implementation requires no additional data collection burden.

These findings should be interpreted within a predictive landscape historically oriented toward mortality. Instruments such as the NHFS and the ASA classification were primarily developed to predict 30-day mortality, for which they demonstrate moderate discrimination.[12,13,30] However, early postoperative complications—which are highly prevalent and serve as the proximate cause of functional decline—have received considerably less dedicated modeling. When existing mortality-oriented tools were applied to this cohort, they exhibited poor discrimination for early composite complications (C statistics ranging from 0.61 to 0.63). The superior performance of the present model underscores the necessity of employing outcome-specific prognostic tools in geriatric surgical care.

Crucially, the methodology applied in this study mitigates a common flaw in prediction modeling. By repeating the LASSO selection step within every bootstrap resample, the reported optimism-corrected estimates account for both coefficient estimation and variable selection. Reporting conventional, uncorrected figures would have substantially overstated the model's expected performance in external populations.

Notably, several retained predictors—specifically polypharmacy, hyponatremia, and hypoalbuminemia—are potentially modifiable. Polypharmacy is a core geriatric syndrome amenable to deprescribing,[26] and hyponatremia is frequently correctable preoperatively once underlying etiologies, such as offending medications or volume depletion, are addressed.[25,31] Although the associations identified in this model are observational and represent markers of underlying physiological vulnerability, they highlight actionable targets for preoperative optimization that warrant prospective evaluation in clinical trials.

Strengths and Limitations

This study has several strengths. First, the model underwent temporal validation using a chronologically distinct cohort. The maintained discrimination (C-statistic, 0.703) provides evidence of reproducibility beyond the initial development period. Second, the model was translated into an integer bedside score utilizing only routinely available variables, allowing for point-of-care assessment without complex computations. This score categorized patients into four risk tiers, with observed complication rates ranging from 1.2% to 18.8%. Third, the derivation cohort met the formally justified sample size threshold based on contemporary criteria, which helps limit the risk of overfitting.

Several limitations should be noted. First, the study was conducted at a single tertiary center utilizing a specific orthogeriatric fast-track pathway; therefore, external validation in independent cohorts is required prior to clinical application. Second, although the overall event count (n = 87) achieved an adequate events-per-variable ratio, it limits the precision of individual coefficients, particularly within the lowest-risk stratum. Third, the composite outcome does not differentiate among specific event types, and competing risks, such as death, were incorporated as

composite components. Finally, the model's moderate overall discrimination limits its utility as a "rule-in" tool. However, the negative predictive value (>98%) suggests potential utility in identifying low-risk patients, though this requires further clinical evaluation.

Conclusions

A prognostic model derived from routine comprehensive geriatric assessment domains and admission laboratory values accurately stratified the risk of early major complications following hip fracture surgery. The model demonstrated superior discrimination compared with existing standard indices and maintained robust performance upon temporal validation. Pending external validation, this tool may facilitate targeted perioperative monitoring, while its modifiable components offer theoretical avenues for preoperative optimization.

Declarations

Ethics approval and consent to participate

The Siriraj Institutional Review Board approved this study (COA Si175/2025) and waived the requirement for informed consent due to the retrospective study design and the use of anonymized data obtained from routine clinical practice.

Consent for publication

Not applicable.

Availability of data and materials

Individual participant data cannot be shared publicly due to institutional ethics and patient privacy restrictions. However, the full prediction model equation, coefficients, and scoring system

are transparently provided in the Supplementary Material to allow for external validation by other researchers.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

US and SS conceptualized and designed the study. All authors acquired, analyzed, or interpreted the data. US and SS drafted the manuscript. VS, DT, KT, and US critically reviewed the manuscript for important intellectual content. US, SS and ST conducted the statistical analysis. US obtained funding. PS, MK, RS, LH, and KL provided administrative, technical, or material support. VS and DT provided supervision. All authors read and approved the final manuscript.

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Figure

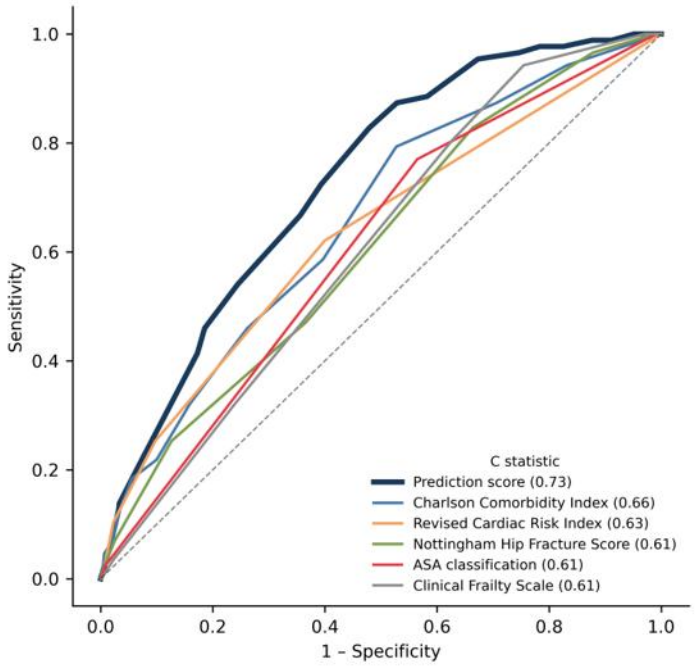

Figure 1. Discrimination of the Prediction Score and Existing Instruments

Receiver operating characteristic curves for the bedside prediction score and 5 comparator instruments applied alone in 1020 patients with 87 events. C statistics are shown in parentheses. The diagonal reference line indicates no discrimination. ASA indicates American Society of Anesthesiologists.

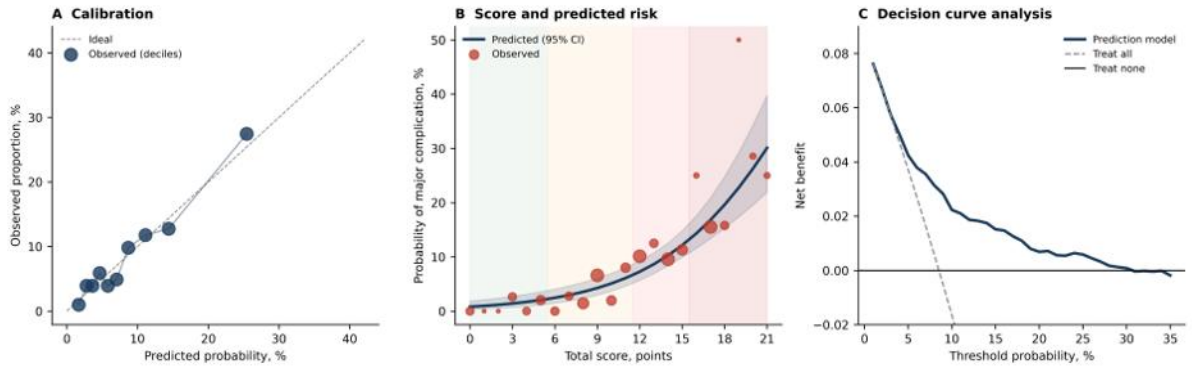

Figure 2. Calibration, Predicted Risk by Score, and Clinical Utility

A, Calibration of the continuous model. Circles represent deciles of predicted risk; circle size is proportional to the number of patients. The dashed line indicates perfect calibration. **B**, Predicted probability of major complication by total score (line, with shaded 95% CI) and observed proportion at each score (circles sized by number of patients). **C**, Decision curve analysis comparing the model with treat-all and treat-none strategies; net benefit is plotted against threshold probability.

Supplementary Files

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