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Prediction of bleeding complications using platelet aggregation testing and thromboelastography in patients undergoing kidney biopsy: a prospective cohort study

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Article

Keywords: prediction model, thromboelastography, platelet aggregation, kidney biopsy, bleeding complications

Posted Date: April 23rd, 2026

DOI: https://doi.org/10.21203/rs.3.rs-9347196/v1

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Additional Declarations: No competing interests reported.

Abstract

Background

Kidney biopsy is an essential procedure for diagnosing kidney diseases. However, bleeding remains a major complication. This study aimed to evaluate predictive factors, including platelet aggregation testing and thromboelastography, and to develop a prediction model to estimate the probability of bleeding complications in patients undergoing kidney biopsy.

Methods

In this prospective cohort study, adult patients (aged ≥ 18 years) with renal failure were enrolled. Platelet aggregation testing and thromboelastography were performed within 24 h prior to kidney biopsy. A prediction model was developed using backward stepwise regression. Model performance was assessed using discrimination and calibration, and internal validation was performed using bootstrap resampling.

Results

A total of 119 patients were included. Bleeding complications occurred in 66 patients. Neutrophil-to-lymphocyte ratio ≥ 15, fibrinogen ≥ 500 mg/dL, time to maximum aggregation of epinephrine ≥ 450 s, and time to maximum aggregation of ristocetin ≥ 420 s were associated with a reduced risk of bleeding complications. In contrast, maximum lysis at 60 min (ML60) in extrinsic pathway thromboelastometry (EXTEM) ≥ 5% was associated with an increased risk of bleeding. The BENREEF model demonstrated good performance, with strong discrimination and calibration, including in internal validation.

Conclusions

Both protective and risk factors for bleeding complications following kidney biopsy were identified. The BENREEF model showed good predictive performance for estimating bleeding risk. However, external validation is required before clinical application.

Background

Renal disease is a common clinical condition. Early diagnosis and treatment can reduce disease progression to end-stage kidney disease and improve survival (1). Kidney biopsy is a medical procedure in which small samples of renal tissue are obtained for the diagnosis of kidney diseases, evaluation of renal function, and monitoring of treatment response. This procedure aids clinicians in making appropriate therapeutic decisions. However, bleeding remains a major complication of kidney biopsy. About 1.4–10.3% of patients undergoing kidney biopsy experience bleeding complications (2–4). The

severity of bleeding varies, ranging from gross hematuria to hypovolemic shock. Patients who develop bleeding complications have an increased risk of mortality (5).

Several factors have been associated with an increased risk of bleeding following kidney biopsy. Patients with renal failure, particularly those with serum creatinine ≥ 2.0 mg/dL, are at higher risk (6, 7). The mechanisms underlying abnormal bleeding in these patients include platelet dysfunction, nitric oxide accumulation, anemia, dialysis-induced vascular changes, and impaired platelet-vessel wall interactions (8, 9). Uncontrolled hypertension is another important risk factor. A systolic blood pressure ≥ 160 mmHg or diastolic blood pressure ≥ 100 mmHg is associated with an increased risk of bleeding in patients undergoing kidney biopsy (10). Therefore, blood pressure should be adequately controlled prior to the procedure to minimize bleeding complications. In addition, thrombocytopenia and coagulopathy are well-recognized risk factors for bleeding during invasive procedures, including kidney biopsy. Thus, the procedure should be performed with caution in patients at high risk of bleeding.

The platelet aggregation test is considered the gold standard for diagnosing platelet dysfunction, including conditions such as Glanzmann thrombasthenia, Bernard–Soulier syndrome, and drug-induced platelet dysfunction. It has also been used to predict bleeding risk in thrombocytopenic patients with acute myeloid leukemia and the risk of recurrent stroke or major bleeding in patients with stroke (11, 12). Thromboelastography (TEG) is a laboratory technique used to assess hemostasis by measuring the viscoelastic properties of whole blood during clot formation and dissolution. It has been shown to predict perioperative bleeding risk and reduce blood transfusion requirements in trauma and surgical settings (13). A limited number of studies have evaluated the utility of the platelet aggregation test or TEG in predicting bleeding risk following kidney biopsy. However, their findings remain inconclusive. Therefore, this study aimed to evaluate predictive factors, including platelet aggregation testing and TEG, for bleeding complications following kidney biopsy and to develop a prediction model to estimate the probability of bleeding in patients undergoing kidney biopsy. Such a model may improve clinical decision-making, reduce bleeding risk, and ultimately improve patient outcomes.

Materials and Methods

Study population

This prospective cohort study was conducted at Songklanagarind Hospital, the largest tertiary care center in Southern Thailand, between June 2020 and July 2024. Patients (age ≥ 18 years) with renal failure, defined as creatinine clearance < 60 mL/min calculated using the Cockcroft–Gault formula, were enrolled prior to undergoing kidney biopsy. Exclusion criteria included: kidney transplant recipients; current use of anticoagulants or antiplatelet agents; prolonged activated partial thromboplastin time (aPTT), prothrombin time/international normalized ratio (PT/INR) > 1.5; platelet count < 100,000 cells/μL; hemodynamic instability; requirement for invasive mechanical ventilation; use of herbal products or medications known to interfere with hemostasis; and uncontrolled hypertension (systolic pressure ≥ 140 mmHg or diastolic pressure ≥ 100 mmHg) prior to kidney biopsy.

This study was approved by the institutional review board of our institution and conducted in accordance with the Declaration of Helsinki (approval number: REC. 63-131-14-1). Written informed consent was obtained from all participants prior to enrollment.

Kidney biopsy procedure

All kidney biopsies were performed based on clinical indications and at the discretion of the treating nephrologist. Percutaneous kidney biopsies were performed under real-time ultrasound guidance in the prone position by experienced radiologists or radiology trainees under direct supervision. An automated spring-loaded biopsy device with a 16-gauge needle was used. A minimum of three core samples were obtained, as determined by the radiologist based on specimen adequacy. Post-biopsy ultrasonography was performed immediately to assess for bleeding complications. Following the procedure, patients remained in the supine position for at least 6 h and were monitored for signs and symptoms of bleeding complications for a minimum of 24 h during hospitalization.

Platelet aggregation test and thromboelastography

Platelet aggregation was assessed using a Helena AggRAM aggregometer (Helena Biosciences, UK) based on the light transmission method. Citrated venous blood samples were stored at room temperature and analyzed within 4 h of collection. Platelet-rich plasma (PRP) was prepared by centrifugation at 200 × g for 10 min, and platelet-poor plasma (PPP) was obtained by further centrifugation at 2,000 × g for 10 min. The platelet count in PRP was adjusted to 200,000–300,000 cells/μL using autologous PPP. Aggregation was induced by adding 25 μL of platelet agonists to 225 μL of PRP. The agonists included adenosine diphosphate (ADP), collagen (5 μg/mL), epinephrine (10 μM), and ristocetin (1.0 mg/mL). The final concentrations of each agonist were applied according to standard protocols. Parameters recorded included primary slope, secondary slope, maximum aggregation, and time to maximum aggregation. Measurements were continuously recorded for 10 min after agonist addition. Internal quality control was performed daily, and instrument calibration and performance verification were conducted according to the manufacturer's instructions.

TEG was performed using a rotational thromboelastometry (ROTEM) delta analyzer (Werfen/Instrumentation Laboratory, Germany). Citrated whole-blood samples were stored at room temperature and analyzed within 60 min of collection. For each assay, 300 μL of blood was mixed with assay-specific reagents and calcium chloride ($CaCl_2$). The EXTEM (extrinsic pathway thromboelastometry), INTEM (intrinsic pathway thromboelastometry), APTEM (aprotinin-modified thromboelastometry), and FIBTEM (fibrin-based thromboelastometry) assays were performed. Parameters recorded included clotting time (CT), clot formation time, α angle, amplitude 10 min after CT, amplitude 20 min after CT, maximum clot firmness, and maximum lysis at 60 min (ML60). All measurements were continuously monitored for at least 60 min. Daily internal quality control and instrument calibration were performed according to the manufacturer's instructions.

Predictors and outcome

Predictors were selected based on literature review and investigator expertise. Cardiovascular diseases included hypertension, diabetes mellitus, dyslipidemia, and myocardial infarction. Baseline patient characteristics and laboratory data were collected within 1 week prior to kidney biopsy. Platelet aggregation testing, TEG, and fibrinogen levels were performed within 24 h before the procedure.

Bleeding events were monitored from the time of kidney biopsy until hospital discharge. Major bleeding was defined as bleeding requiring therapeutic intervention, requiring blood transfusion, associated with a decrease in hemoglobin ≥ 1 g/dL, or resulting in death. Minor bleeding included gross hematuria, perinephric hematoma, or bleeding that did not require therapeutic intervention or blood transfusion (14).

Statistical analysis

All statistical analyses were performed using R software (version 4.3.2). Categorical variables were presented as frequencies and percentages, and continuous variables as medians with interquartile ranges (IQR). Comparisons between patients with and without bleeding complications were performed using chi-square test, Student's *t*-test, or Fisher's exact test, as appropriate. Maximally selected rank statistics were used to determine optimal cutoff values for continuous variables. Univariate and multivariate logistic regression analyses were conducted to identify predictors of bleeding complications following kidney biopsy. Variables with $P < 0.05$ in univariate analysis were included in the multivariable model.

A prediction model was developed using backward stepwise regression, and the model with the lowest Akaike Information Criterion (AIC) was selected. Model performance was evaluated using the area under the receiver operating characteristic curve (AUC) for discrimination and calibration plots for calibration.

Internal validation was performed using bootstrap resampling (1,000 iterations). Model performance was assessed using AUC and calibration plots in the bootstrap samples.

This study adhered to the Transparent Reporting of a multivariable prediction model for Individual Prognosis Or Diagnosis (TRIPOD) guidelines (15).

Results

A total of 121 patients were enrolled in this study. Two patients were excluded due to immediate contraindications on the day of kidney biopsy. Consequently, 119 patients were included in the final analysis. The median age was 45.3 years, with a female predominance (54.6%). The median time from symptom onset to kidney biopsy was 90.0 days. Approximately 58.0% of patients had cardiovascular disease. The median hematocrit (Hct) and platelet count were 32.7% and 261,000 cells/μL, respectively. The median neutrophil-to-lymphocyte ratio (NLR) was 3.83, and the median serum creatinine level was 2.06 mg/dL. Most baseline characteristics were similar between patients with and without bleeding

complications (Table 1). However, fibrinogen levels were significantly higher in patients without bleeding complications than in those with bleeding complications.

Table 1
Baseline characteristics in 119 patients who underwent kidney biopsy according to bleeding complications

Characteristics	Patients with bleeding complications (N = 66) Number (%)	Patients without bleeding complications (N = 53) Number (%)	*P* value
Age (years), median (IQR)	45.3 (31.1,54.9)	45.3 (34.5,59.8)	0.395
Gender (female)	39 (59.1)	26 (49.1)	0.275
Weight (kg), median (IQR)	63.3 (56.8,70.2)	67.7 (57.2,78.2)	0.137
Height (cm), median (IQR)	160.0 (152.0,165.0)	160.0 (155.0,169.0)	0.436
Time from symptoms to kidney biopsy (days), median (IQR)	90.0 (47.5,240.0)	90.0 (41.0,218.0)	0.927
Underlying disease	53 (80.3)	44 (83.0)	0.704
Cardiovascular disease	37 (56.1)	32 (60.4)	0.635
Hematologic disease	7 (10.6)	5 (9.4)	0.833
Liver disease	2 (3.0)	2 (3.8)	1.000
Systolic blood pressure, median (IQR)	132.0 (124.2,138.0)	130.0 (120.0,136.0)	0.349
Hemoglobin (g/dL), median (IQR)	10.5 (9.4,12.2)	11.1 (9.7,11.8)	0.562
Hematocrit (%), median (IQR)	32.7 (28.3,37.8)	33.0 (29.3,35.9)	0.571
Platelet (cells/μL), median (IQR)	261000 (204800,318800)	263000 (201000,329000)	0.783
White blood cell (cells/μL), median (IQR)	8815 (6510,10910)	8250 (6360,10730)	0.409
Neutrophil to lymphocyte ratio, median (IQR)	3.3 (2.2,7.1)	4.2 (2.6,12.8)	0.190
aPTT (s), median (IQR)	25.1 (21.5,29.1)	25.1 (23.7,27.1)	0.785
PT(s), median (IQR)	1.00 (0.93,1.05)	1.01 (0.93,1.10)	0.421
Fibrin (mg/dL), median (IQR)	480.7 (336.1,627.7)	600.2 (452.8,833.5)	0.017
Blood urea nitrogen (mg/dL), median (IQR)	30.3 (21.0,49.5)	32.2 (22.1,49.1)	0.989
Creatinine (mg/dL), median (IQR)	2.3 (1.1,4.2)	2.0 (1.3,2.8)	0.474

aPTT, activated partial thromboplastin time; cm, centimeters; dL, deciliters; IQR, interquartile range; kg, kilograms; mg, milligrams; PT, prothrombin time.

Platelet aggregation test and thromboelastography

In the platelet aggregation test, the median maximum aggregation percentages were 88.0%, 91.2%, 88.5%, and 89.3% for ADP, collagen, epinephrine, and ristocetin, respectively. These values did not differ significantly between patients with and without bleeding complications. The primary and secondary slopes for all agonists were also similar between the two groups. However, the median time to maximum aggregation of epinephrine and ristocetin was shorter in patients with bleeding complications (Table 2).

Regarding TEG, the median ML60 in EXTEM was higher in patients with bleeding complications. Other TEG parameters, including INTEM, APTEM, and FIBTEM, were comparable between patients with and without bleeding complications (Table 3).

Table 2
Platelet aggregation test of 119 patients before kidney biopsy

Platelet aggregation test	Patients with bleeding complication (N = 66) Median (IQR)	Patients without bleeding complication (N = 53) Median (IQR)	*P* value
Adenosine diphosphate			
Primary slope (%/min)	123.6 (106.8,143.2)	126.3 (104.4,136.7)	0.925
Secondary slope (%/min)	24.4 (21.3,27.5)	24.3 (21.6,27.2)	0.783
Maximum aggregation (%)	87.5 (80.9,92.0)	88.9 (83.2,92.0)	0.499
Time to maximum aggregation (s)	366.5 (320.5,411.8)	364.0 (322.0,478.0)	0.301
Collagen			
Primary slope (%/min)	23.7 (2.1,29.1)	24.1 (2.1,31.0)	0.874
Secondary slope (%/min)	133.0 (119.6,152.6)	141.9 (114.9,154.4)	0.998
Maximum aggregation (%)	90.8 (87.2,93.4)	91.7 (88.6,93.5)	0.243
Time to maximum aggregation (s)	429.0 (362.0,490.8)	429.0 (362.0,548.0)	0.539
Epinephrine			
Primary slope (%/min)	72.4 (38.1,111.1)	61.0 (46.7,78.4)	0.334
Secondary slope (%/min)	26.2 (21.2,29.8)	25.5 (23.0,36.5)	0.225
Maximum aggregation (%)	86.8 (80.1,91.1)	90.0 (84.0,92.7)	0.065
Time to maximum aggregation (s)	489.5 (438.5,579.8)	550.0 (486.0,582.0)	0.039
Ristocetin			
Primary slope (%/min)	86.5 (61.3,104.1)	84.7 (65.5,105.4)	0.961
Maximum aggregation (%)	88.2 (84.8,91.8)	89.7 (84.8,93.4)	0.324
Time to maximum aggregation (s)	316.5 (251.8,370.0)	336.0 (260.0,432.0)	0.023

IQR, interquartile range.

Table 3
Thromboelastography of 119 patients before kidney biopsy

Thromboelastography	**Patients with bleeding complication (N = 66)** **Median (IQR)**	**Patients without bleeding complication (N = 53)** **Median (IQR)**	***P* value**
EXTEM			
Coagulation time (s)	49.0 (44.0,52.0)	48.0 (38.0,54.3)	0.452
Clot formation time (s)	60.5 (44.3,77.8)	54.0 (42.3,77.5)	0.575
α angle (degree)	80.0 (75.3,82.8)	80.0 (76.0,82.0)	0.824
Amplitude 10 min after CT (mm)	61.0 (55.3,67.0)	65.0 (55.8,69.3)	0.444
Amplitude 20 min after CT (mm)	66.5 (59.3,70.8)	69.0 (61.0,73.3)	0.209
Maximum clot firmness (mm)	68.0 (61.3,72.0)	69.5 (62.8,75.0)	0.252
Maximum lysis within 60 min (%)	9.0 (5.0,12.0)	6.0 (3.0,11.0)	0.049
INTEM			
Coagulation time (s)	175.5 (146.2,206.0)	173.5 (136.8,221.8)	0.797
Clot formation time (s)	64.0 (51.3,82.0)	63.0 (49.0,84.0)	0.717
α angle (degree)	78.0 (75.0,79.8)	78.0 (74.8,81.0)	0.590
Amplitude 10 min after CT (mm)	58.0 (53.3,64.8)	62.0 (55.0,66.3)	0.391
Amplitude 20 min after CT (mm)	64.0 (60.0,70.0)	67.0 (60.8,71.3)	0.366
Maximum clot firmness (mm)	64.5 (61.0,71.0)	67.0 (60.8,72.0)	0.554
Maximum lysis within 60 min (%)	4.0 (3.0,7.8)	4.0 (3.0,7.0)	0.861
APTEM			
Maximum clot firmness (mm)	8.0 (4.0,49.0)	5.5 (4.0,64.0)	0.898
FIBTEM			
Amplitude 10 min after CT (mm)	21.0 (16.0,26.8)	24.0 (18.8,31.3)	0.080

Thromboelastography	Patients with bleeding complication (N = 66)	Patients without bleeding complication (N = 53)	*P* value
	Median (IQR)	Median (IQR)	
Amplitude 20 min after CT (mm)	22.5 (17.0,28.8)	25.0 (19.0,32.3)	0.167
Maximum clot firmness (mm)	23.0 (17.0,31.8)	26.0 (20.0,33.3)	0.142

CT, coagulation time; mm, millimeters; s, seconds.

Bleeding complications

Among the 119 patients who underwent kidney biopsy, 66 (55.5%) experienced bleeding complications. Major bleeding occurred in approximately 10.1% of patients. Specifically, four patients required therapeutic intervention, two patients experienced a significant decline in Hct, and four patients required blood transfusion. Minor bleeding occurred in 54 patients (45.4%), including 52 cases of perinephric hematoma and 2 cases of gross hematuria. No deaths occurred during the study period.

Factors associated with bleeding complications

In the univariate analysis, body weight, NLR, fibrinogen, serum creatinine, time to maximum aggregation for ADP, collagen, epinephrine, and ristocetin, primary and secondary slopes of epinephrine, coagulation time, and ML60 in EXTEM were associated with bleeding complications.

In the multivariate analysis, NLR ≥ 15, fibrinogen ≥ 500 mg/dL, time to maximum aggregation of epinephrine ≥ 450 s, and time to maximum aggregation of ristocetin ≥ 420 s were identified as protective factors against bleeding complications. In contrast, ML60 in EXTEM ≥ 5% was independently associated with an increased risk of bleeding complications in patients undergoing kidney biopsy (Supplementary Table S1).

Prediction model generation for bleeding complications

A prediction model (BENREEF model) was developed using backward stepwise regression to estimate the risk of bleeding complications in patients undergoing kidney biopsy (Supplementary Table S2). The model included Body weight, time to maximum aggregation of Epinephrine, Neutrophil-to-lymphocyte ratio, time to maximum aggregation of Ristocetin, coagulation time in EXTEM, ML60 in EXTEM, and Fibrinogen level.

A nomogram of the prediction model is presented in Fig. 1. The model demonstrated good discriminative ability, with an AUC of 0.88 (95% CI: 0.81–0.95) (Fig. 2). The calibration plot indicated good agreement between predicted and observed outcomes (Fig. 3).

Internal validation of prediction model

Internal validation was performed using bootstrap resampling with 1,000 iterations. The validated model showed an AUC of 0.88 (95% CI: 0.80–0.94). The calibration plot also demonstrated good calibration (Supplementary Fig. S1).

Discussion

In this study, approximately 10.1% of patients who underwent kidney biopsy experienced major bleeding. NLR ≥ 15, fibrinogen ≥ 500 mg/dL, time to maximum aggregation of epinephrine ≥ 450 s, and time to maximum aggregation of ristocetin ≥ 420 s were associated with a decreased risk of bleeding complications. In contrast, ML60 in EXTEM ≥ 5% was associated with an increased risk of bleeding complications in patients undergoing kidney biopsy. The BENREEF model demonstrated good performance in predicting the probability of bleeding in these patients.

The incidence of major bleeding complications for kidney biopsy in this study was higher than that reported in previous studies (10.1% vs. 0.9–7.2%) (4, 16, 17). All kidney biopsies were performed by experienced radiologists or supervised trainees according to standard protocols. The higher incidence observed in this study may reflect a population with a greater baseline bleeding risk. Additionally, variations in the definition of major bleeding across studies may contribute to differences in reported incidence. Minor bleeding occurred in 45.4% of patients, predominantly as asymptomatic perinephric hematoma, which is higher than the 8.9–17.2% reported previously (14, 16). This increased incidence may be explained by routine post-kidney biopsy ultrasonography, enabling detection of otherwise asymptomatic hematomas.

This study identified seven predictors associated with bleeding risk following kidney biopsy. NLR reflects the balance between innate and adaptive immune responses (18). Interestingly, a high NLR was associated with a reduced risk of bleeding complications. Elevated NLR indicates increased systemic inflammation, which promotes a procoagulant state through cytokine-mediated upregulation of tissue factor, resulting in increased thrombin generation and fibrin formation. It may also enhance platelet activation, suppress natural anticoagulant pathways, and inhibit fibrinolysis (19, 20). These mechanisms may reduce bleeding risk but may also increase the risk of thrombosis. Previous studies have not evaluated the association between elevated NLR and bleeding risk in kidney biopsy. However, elevated NLR has been associated with increased bleeding complications in other clinical settings, including gastrointestinal bleeding in acute ischemic stroke, Henoch–Schönlen purpura, major bleeding in atrial fibrillation, and rebleeding in aneurysmal subarachnoid hemorrhage (21–24). The underlying mechanisms of hemostasis in patients with elevated NLR undergoing kidney biopsy remain unclear and warrant further investigation.

Body weight was not significantly associated with bleeding risk in this study, consistent with previous reports (25, 26), but it remained an important component of the prediction model. This highlights that

predictors in multivariable models do not necessarily represent independent risk factors. Fibrinogen plays a central role in the coagulation cascade and is essential for maintaining hemostasis (27). Patients with afibrinogenemia, hypofibrinogenemia, or dysfibrinogenemia are at increased risk of spontaneous and perioperative bleeding (28, 29). Low fibrinogen levels have also been associated with bleeding during medical interventions (30). In this study, higher fibrinogen levels (≥ 500 mg/dL) were associated with a reduced risk of bleeding following kidney biopsy. However, prophylactic elevation of fibrinogen to this threshold is not recommended, as excessively high levels may increase thrombotic risk. Instead, patients with fibrinogen levels < 500 mg/dL should be closely monitored.

Patients with renal failure are at risk of uremia-related platelet dysfunction, which contributes to bleeding. Platelet function analyzers are commonly used to assess platelet-related bleeding risk in kidney biopsy. Prolonged closure time has been associated with increased bleeding risk in some studies (31, 32), although others have reported no significant association (33, 34). In this study, light transmission aggregometry, the gold standard for assessing platelet function (35), was used. Maximum platelet aggregation was not associated with bleeding risk. Shorter time to maximum aggregation of epinephrine and ristocetin was associated with an increased risk of bleeding complications. This may reflect dysregulated platelet activation kinetics and impaired clot stability, leading to unstable thrombus formation and premature disaggregation. However, clinical evidence supporting this association remains limited and requires further validation.

TEG assesses the viscoelastic properties of clot formation in real time and is widely used to evaluate bleeding risk and guide transfusion strategies (36). EXTEM reflects the extrinsic coagulation pathway and may be particularly useful in this context. Evidence for the use of TEG in predicting bleeding during kidney biopsy remains limited and inconsistent. Davis et al. reported an association between abnormal TEG findings and bleeding in transplant kidney biopsies, whereas Gal-Oz et al. found no such association in native kidney biopsies (37, 38). In the present study, prolonged coagulation time (CT) and increased ML60 in EXTEM were associated with an increased risk of bleeding complications. These findings suggest delayed clot formation and enhanced fibrinolysis, respectively, both of which contribute to clot instability and increased bleeding risk.

We developed a BENREEF model to predict bleeding risk in patients undergoing kidney biopsy. This model incorporates seven predictors, including parameters from platelet aggregation testing and TEG, and represents the first model to integrate these two hemostatic assessments in this clinical setting. The model demonstrated strong predictive performance across a wide range of bleeding probabilities ranging from 5% to 99%. However, no specific cutoff was established to guide clinical decision-making. We suggest that patients with a bleeding probability ≥ 20% should undergo careful evaluation before proceeding with kidney biopsy. Modifiable risk factors should be optimized prior to the procedure, and patients should be closely monitored during the perioperative and postoperative periods. Early detection and management of bleeding may reduce complications. The model was internally validated using bootstrap resampling and demonstrated good discrimination and calibration. However, external validation is necessary to confirm its generalizability.

This study has several limitations. First, it was conducted at a single center, which may limit generalizability and introduce the risk of model overfitting. Although internal validation demonstrated good performance, external validation is required. Second, the incidence of bleeding complications was higher than that reported in previous studies, which may reflect higher baseline risk or increased detection due to routine ultrasonography. Third, the study population consisted exclusively of Asian patients, and the applicability of the model to other populations requires further investigation.

Conclusions

Neutrophil-to-lymphocyte ratio ≥ 15, fibrinogen ≥ 500 mg/dL, time to maximum aggregation of epinephrine ≥ 450 s, and time to maximum aggregation of ristocetin ≥ 420 s were associated with a reduced risk of bleeding complications following kidney biopsy, whereas ML60 in EXTEM ≥ 5% was associated with an increased risk. The BENREEF model demonstrated good predictive performance for estimating bleeding risk in this population. However, external validation is required before routine clinical implementation.

Abbreviations

ADP
Adenosine diphosphate
AIC
Akaike Information Criterion
aPTT
Activated partial thromboplastin time
AUC
Area under the curve
BENREEF
(Model name; expand if defined by authors)
CI
Confidence interval
CT
Coagulation time
EXTEM
Extrinsic pathway thromboelastometry
FIBTEM
Fibrin-based thromboelastometry
Hct
Hematocrit
INTEM
Intrinsic pathway thromboelastometry
IQR

Interquartile range
ML60
Maximum lysis at 60 minutes
NLR
Neutrophil-to-lymphocyte ratio
PRP
Platelet-rich plasma
PPP
Platelet-poor plasma
PT
Prothrombin time
PT/INR
Prothrombin time/International normalized ratio
ROC
Receiver operating characteristic
TEG
Thromboelastography

Declarations

Ethics approval and consent to participate

This study was approved by the institutional review board of Songklanagarind Hospital and conducted in accordance with the Declaration of Helsinki (approval number: REC. 63-131-14-1). Written informed consent was obtained from all participants prior to enrollment.

Consent for publication

Not applicable.

Competing interests

The authors declare no conflict of interest.

Funding

This study was supported by the Faculty of Medicine, Prince of Songkla University (grant number REC. 63-131-14-1).

Author Contribution

N.W. and P.S. designed the study. All authors collected the data. PS analyzed the data, interpreted the results, and drafted the manuscript. All authors critically revised the manuscript for intellectual content, approved the final version for publication, and agreed to be accountable for all aspects of the study.

Acknowledgement

We would like to thank the Division of Information Technology at Songklanagarind Hospital and Prince of Songkla University for their support.

Data Availability

The datasets are available from the corresponding author upon request.

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Figures

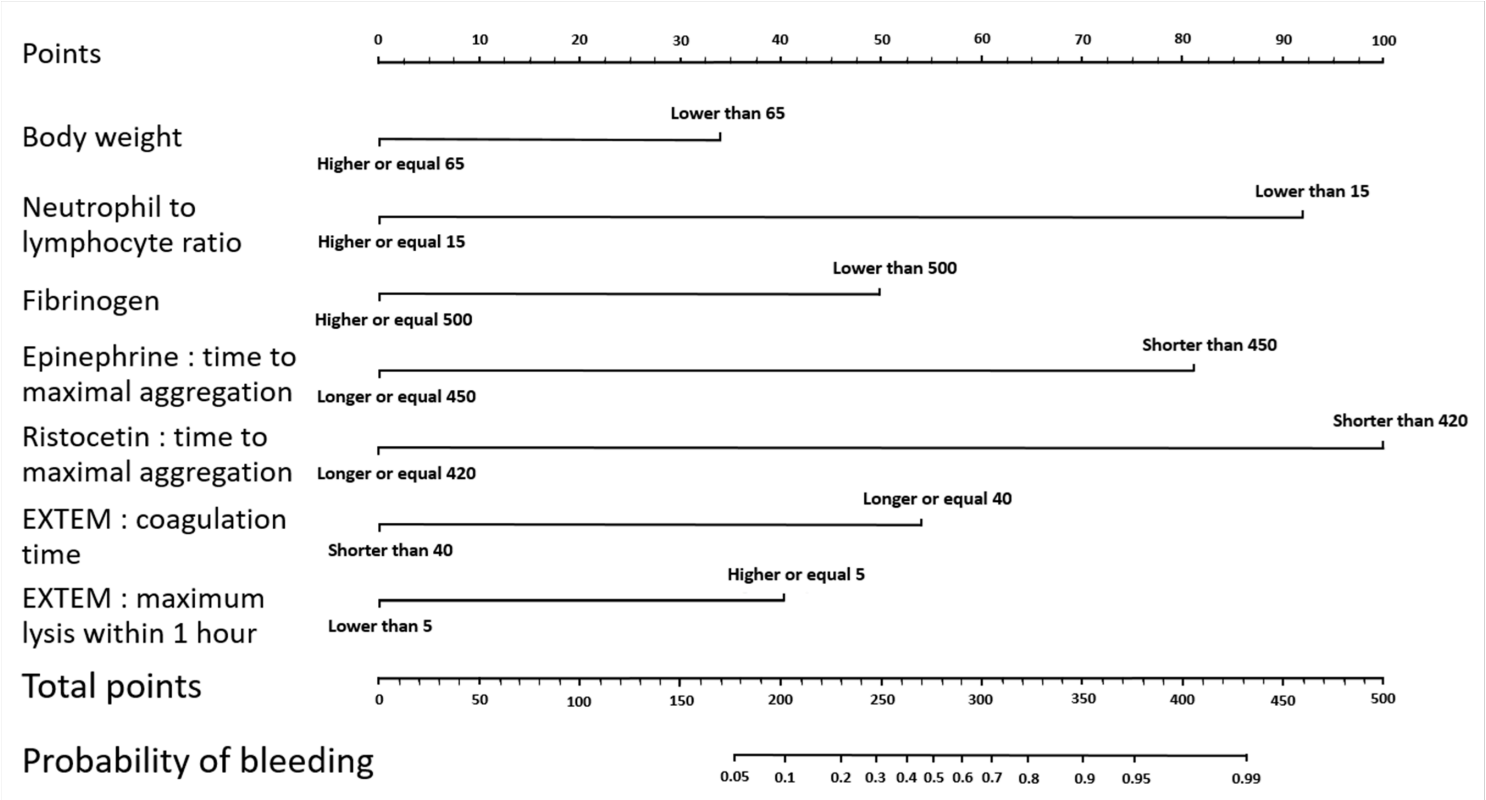


Figure 1

A nomogram of the prediction model (BENREEF model) to predict the probability of bleeding risk in patients undergoing kidney biopsy

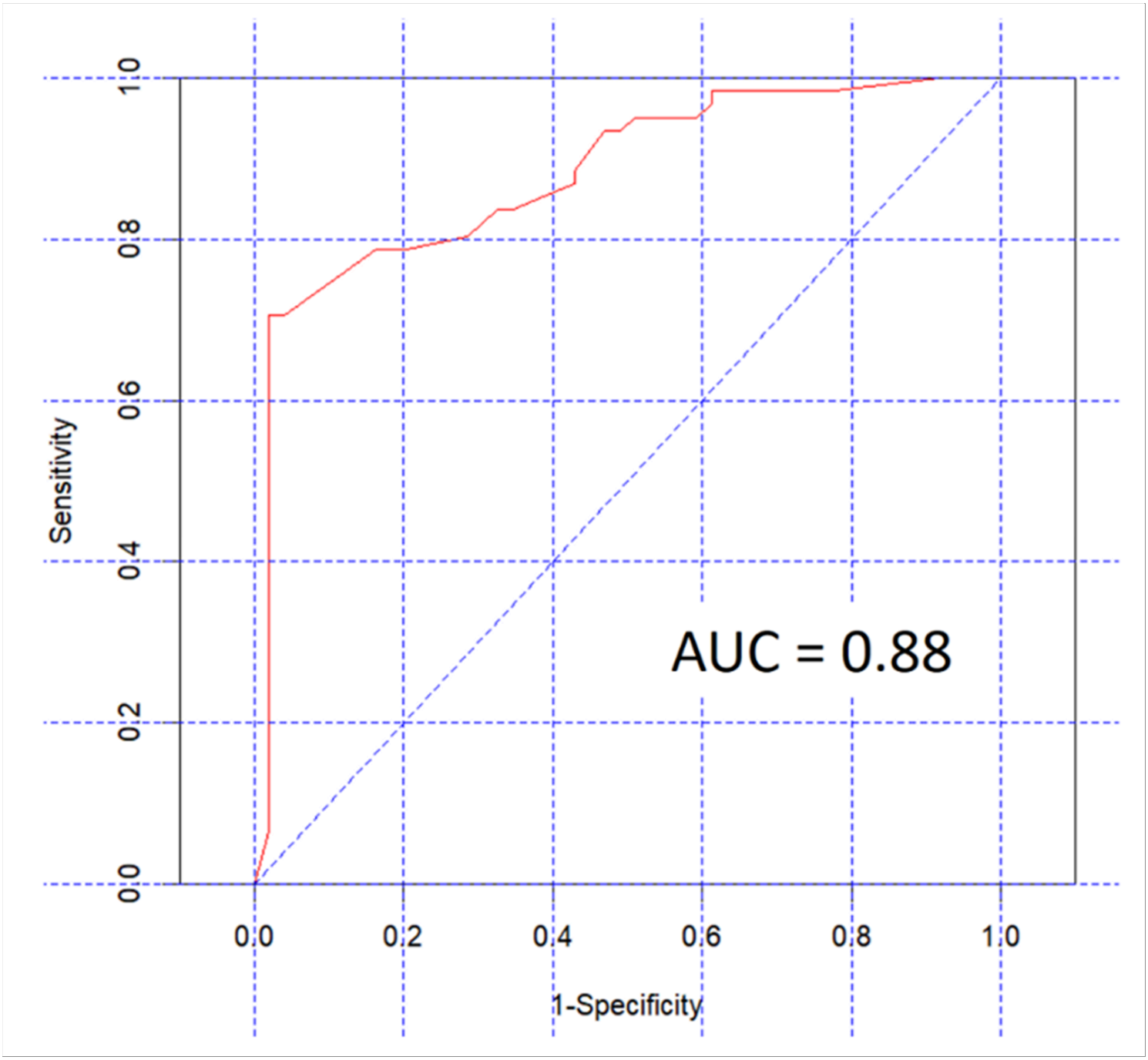


Figure 2

The area under the curve of the BENREEF model.

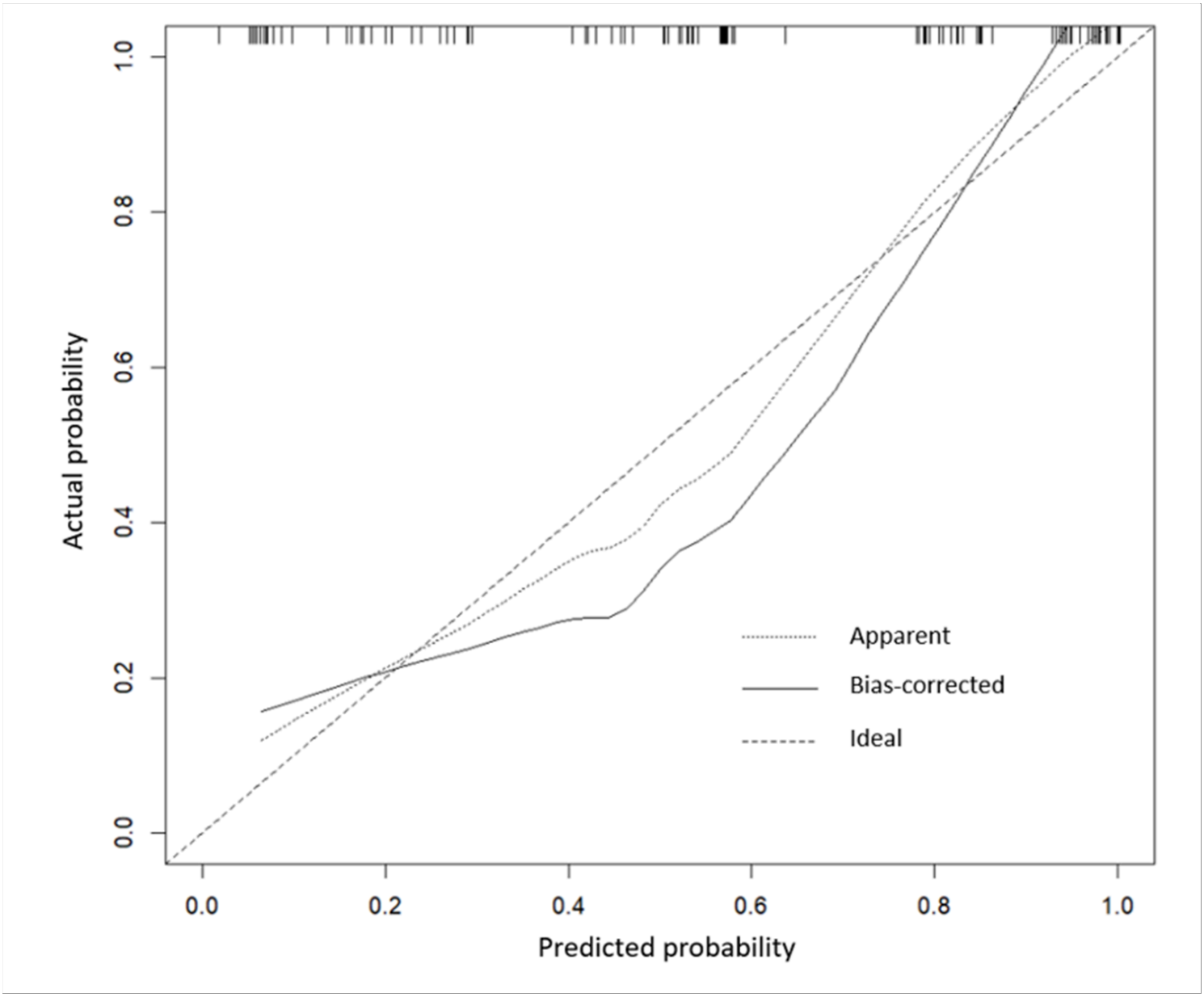


Figure 3

The calibration plot of the BENREEF model.

Supplementary Files

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