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A Proposed Scoring System to Estimate Complications and Prolonged Hospitalization After Carotid Stenting: A Pilot Study

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Abstract

Introduction:

Prolonged hospitalization following carotid artery stenting (CAS) increases healthcare costs and patient morbidity. Predictive models specific to interventional radiology are lacking.

Materials and methods:

We retrospectively analyzed patients who underwent CAS between 2012 and 2020. Patients with carotis near-occlusions, underwent cardiac surgery after CAS, bilateral CAS stenting in the same session and patients with missed data were excluded. 386 patients were eligable for the final analyses having pre-follow-up imagings/recordings. A novel scoring system—the Ankara University Risk Analysis and Scoring System—was developed to predict prolonged hospitalization based on clinical and procedural factors. The proposed risk factors used for the assessment were; advanced age(> 80years), symptomatic status, pulmonary disease, elevated creatinine levels, severe contralateral carotid stenosis, longer intervention times and long atherosclerotic plaque(> 2cm)/irregular plaque surface.

Results:

87 patients (22.5%) needed prolonged hospitalizations (> 1days) regardless of experiencing any kinds of complications and 30 days neurological complications rates were 4.7% (18patients). 3.1% (12patients) of the patients had non-neurologic and 2.3% (9patients) of the patients had transient complications. A score ≥ 9 identified patients at high risk for complications and extended hospitalization with acceptable sensitivity and specificity values. Besides a more compact scoring system was also proposed with less factors included in the scoring (≥ 3 for prolonged hospitalization, ≥ 4 for complications). ROC analysis demonstrated high predictive performance for both systems (AUC = 0.647–0.730, $p < 0.001$).

Conclusion:

Our proposed scoring system shows promise in identifying patients at increased risk for complications and prolonged hospitalization following CAS. Further validation in larger, multi-center cohorts is warranted to confirm its clinical utility.

Introduction

Prolonged hospitalization is a significant concern for both patients and the healthcare system. It is typically defined as an extended hospital stay and affects approximately 2% of all hospitalized patients (1). Its occurrence may be related to patient-specific factors or aspects of treatment (2). Although the proportion of patients experiencing prolonged hospitalization is relatively small, it substantially

increases healthcare costs, places additional strain on the system, and contributes to higher in-hospital mortality rates (3).

Prolonged hospital stay have been studied across various medical specialties, with numerous studies proposing different scoring systems to predict this undesired outcome (4). Definitions of prolonged hospitalization vary in the literature, ranging from stays of more than two days to those exceeding 21 days, depending on the clinical context (1, 5). The concept remains somewhat abstract, as it may also refer to hospital admissions exceeding one day following procedures typically considered outpatient.

Several authors have attempted to perform major procedures in outpatient settings to enhance the quality of care and demonstrate innovation in medical practice (6–8). Even complex surgeries, such as craniotomies, have been reported as outpatient procedures, with success rates reaching up to 97% (9). While researchers around the world have reported promising outcomes in outpatient surgeries, the data often fall short of providing adequate criteria for patient selection, partly due to medicolegal concerns (6–9).

Although various studies suggest that outpatient procedures could be safely extended to broader patient populations, a noticeable gap between these claims and real-world clinical practice remains. Data on optimal patient selection for outpatient procedures remain inconclusive. Additionally, prolonged hospitalizations are frequently associated with post-procedural morbidity and can be predicted with over 80% accuracy in some models (10). Despite the wealth of data in the surgical literature, there is currently no definitive evidence in the interventional radiology (IR) literature regarding predictors of prolonged hospitalization.

Patients with multiple risk factors and comorbidities are more prone to complications than the general population. It is well established that the accepted rate of neurological complications following carotid artery stenting, whether in symptomatic or asymptomatic patients, ranges from 2% to 6% (11). Some authors have proposed scoring systems to assess the risk of prolonged hospitalization (12, 13). These models often incorporate key predictors of neurological complications, including diabetes, hyperlipidemia, and advanced age (≥ 80 years) (12–14).

In this study, we analyzed a large cohort of patients undergoing carotid artery stenting. The objective of this preliminary investigation is to propose a scoring system to better identify factors associated with complications, whether due to neurological events or other complications, resulting in prolonged length of stay.

Materials and methods

Study design and population

In this retrospective study, we reviewed a prospectively maintained database of all consecutive patients who underwent carotid angioplasty and stenting (CAS) between January 2012 and January 2020.

Institutional review board approval was obtained (I11-888-24) and has therefore been performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki and its later amendments. All patients gave informed consent prior to invasive procedures. All procedures were performed at Ankara University by the vascular interventional radiology team having over 10 to 40 years of experience in this field (ECC, SB). Patients were excluded if they met any of the following criteria: treatment of carotid near-occlusion with/without a string sign, undergoing cardiac surgery after CAS, bilateral CAS performed in the same session.

DSA procedure and Peri-procedural medical therapy

Carotid stenting procedures were performed with local anesthesia and the patients' vital signs were followed-up by the anesthesia team. A two channel near infrared spectroscopy (NIRS) device (Medtronic, USA) was used for the patients with bilateral significant stenosis (combined > 160%), symptomatic patients, and patients with unilateral high-grade stenosis (> 90%) to better understand and monitor the cranial flow changes after stent implantations by the anesthesia team. Technique and institutional protocols were detailed elsewhere (15).

All patients were treated with dual antiplatelet therapy according to our institutional protocol. For patients with atrial fibrillation or a history of cardiac valve replacement, antithrombotic therapy was individualized based on the most up-to-date institutional treatment protocols (15).

Outcomes and definitions

All patients who underwent CAS were evaluated for the presence of neurological and non-neurological complications. For each patient, we recorded: (i) occurrence and type of complications, (ii) complication details, (iii) significant non-transient neurological complications, and (iv) prolonged hospitalization, defined as a hospital stay > 24 hours after the index procedure day. Hospitalizations occurring within 30 days after discharge were not classified as prolonged hospitalization for the purposes of this study.

Scoring system proposed to estimate prolonged hospitalization and complications:

Several scoring systems, such as the Charlson Comorbidity Index, are used to identify patients with high complications risk compared to the general population. These tools help practitioners in the assessment of risks before interventions and inform caregivers about potential adverse outcomes. The Siena Scoring System, which has been validated in the literature, is a tool used to identify patients at higher risk of neurological events after performing CAS (12, 16).

In this study, we have applied our newly developed risk tool based on our experience, the Ankara University Risk Analysis and Scoring System, to assess risk and predict outcomes (Table 1). Prolonged

hospitalization, 30-day all-complication rates, and serious neurological complication rates were compared across categories of the proposed score. After identifying the four most significant predictors, we developed a compact four-item score to predict prolonged hospitalization and complications (Table 2). We also constructed multivariable regression models using these four predictors and evaluated model performance, including weighted prediction based on regression coefficients.

Table 1
Proposed risk scoring system and included parameters with corresponding points

Parameter	Description	Points
Concomitant parameters		
Body mass index (BMI)	Obesity indicator (> 30)	1
Any kind of acute or chronic pulmonary disease	Presence of pulmonary disease	1
Hypertension and/or hyperlipidemia	Presence of the conditions	1
Coronary artery disease and/or peripheral arterial disease	Presence of the conditions	1
Patient age > 80 years	Patients older than 80 years	2
Diabetes mellitus, liver disease, malignancy	Presence of diabetes, liver disease, malignancy	2
Creatinine level > 1.2 mg/dl	Elevated creatinine levels	2
Prior (> 1month) disabling/minor stroke and/or TIA ≤ 1 month before the procedure	History of stroke or recent TIA	2
DSA results an procedure related parameters		
Carotid stenosis > 80%	Significant carotid artery stenosis (> 80%)	1
Bilateral carotid artery stenosis	Significant stenosis (> 70%) in both carotid arteries	1
Contrast media volume	> 150 ml	2
Procedure duration	> 40 minutes	2
Carotid plaque morphology and plaque length	Abnormal plaque characteristics and plaque length > 2 cm	2
Risk classification		
Low risk: 0–8 points (for prolonged hospitalization/neurological complications), 0–10 points (for all-cause complications)		
High risk: 9–20 points (for prolonged hospitalization/neurological complications), 11–20 points (for all-cause complications)		

Table 2
Compact proposed risk scoring system and included parameters with corresponding points

Parameter	Description	Points
Concomitant parameters		
Hypertension and/or hyperlipidemia	Presence of the conditions	1
Coronary artery disease and/or peripheral arterial disease	Presence of the conditions	1
Diabetes mellitus, liver disease, malignancy	Presence of diabetes, liver disease, malignancy	2
Creatinine level > 1.2 mg/dl	Elevated creatinine levels	2
Risk classification		
Low risk: 0–3 points (for all-cause/neurological complications), 0–2 points (for prolonged hospitalization)		
High risk: 4–6 points (for all-cause/neurological complications), 3–6 points (for prolonged hospitalization)		

Using the proposed scoring system described in this article, we aimed to identify, understand, and assess high-risk patients undergoing CAS, with the goal of improving the quality of care. We defined prolonged hospitalization as any hospital stay lasting more than 24h post the initial treatment day. Hospitalizations occurring within 30 days following the initial discharge CAS were not considered prolonged hospitalizations for the purposes of this study.

Statistical Analysis

Categorical variables are presented as counts and percentages. Continuous variables are presented as mean ± standard deviation (SD) and median (range), as appropriate. A two-sided p-value < 0.05 was considered statistically significant. Rates of prolonged hospitalization, 30-day overall complications, and neurological complications across risk factors were compared using chi-square tests. Binary multivariable logistic regression analyses were performed to predict prolonged hospitalization and complications. Model performance was assessed using area under the ROC curve (AUC), and statistical significance was reported accordingly. ROC curve analyses were also performed to evaluate the discriminative performance of the scoring systems. Potential cut-offs were derived from ROC analyses with the highest Youden's J Index and sensitivity, specificity, positive predictive value (PPV) and negative predictive value (NPV) were calculated for each cut-off. All analyses were performed using IBM SPSS Statistics (version 27; IBM, Chicago, IL, USA).

Results

Patient Population and Descriptive Data

A total of 386 patients (275 men, 111 women) were included. The median age was 72 years (range, 40–96). Among pre-treatment risk factors, 95 patients (24.6%) had a BMI > 30; 36 (9.3%) had known lung disease; 265 (68.7%) had hyperlipidemia and/or hypertension; 227 (58.8%) had coronary and/or peripheral arterial disease; 141 (36.5%) had diabetes mellitus, liver disease, and/or a history of malignancy; and 167 (43.3%) had a serum creatinine level > 1.2 mg/dL. In addition, 263 patients (68.1%) had a history of ischemic stroke or transient ischemic attack, and 77 (19.9%) were older than 80 years. The median stenosis of the treated artery was 87% (range, 50–99). Overall, 169 patients (43.8%) had bilateral carotid artery stenosis > 70%, 280 (72.5%) had stenosis > 80%, and 312 (80.8%) had abnormal plaque morphology and/or plaque length > 2 cm. Contrast volume > 150 mL was used in 14 patients (3.6%), and procedure duration exceeded 40 minutes in 16 patients (4.1%).

During follow-up, 87 patients (22.5%) required prolonged hospitalization regardless of presence of complications (> 1 day) after CAS. Thirty-day complications occurred in 39 patients (10.1%). Of these, 18 (4.7%) experienced ischemia-related neurological complications, and 9 (2.3%) had transient ischemic symptoms and/or hypotension. Among these neurological complications, six patients presented with extremity weakness and had cerebral ischemia evidenced on DWI MRI. Five patients had speech difficulty or aphasia. One patient had persistent vomiting and ischemia in the right parietal lobe. The remaining patients presented with loss of orientation and/or syncope and also had cerebral ischemia evidenced on DWI MRI. Among the patients with severe complications, four deaths occurred during subsequent hospitalization after treatment. Of these, one patient developed loss of orientation and hyponatremia on the same day as the treatment and later died due to septic shock. One patient was admitted to the emergency department one week after treatment with deterioration in general condition and was found to have bilateral acute millimetric ischemic infarcts. During follow-up in the neurological intensive care unit, the patient developed widespread ischemia and died two months after treatment. One patient presented with right arm weakness on the day of treatment and had millimetric acute ischemic foci in the left frontoparietal cortex; however, no occlusion was detected in the carotid stent in CT angiography. Six days after treatment, the patient was admitted with acute coronary syndrome and subsequently underwent coronary artery bypass surgery. However, the patient did not recover in the postoperative intensive care unit and died due to bilateral cerebral infarcts. Finally, one patient with preoperative neurological symptoms experienced significant worsening of ischemic symptoms on the day of treatment, with progression of right cerebral ischemia on DWI. The patient underwent decompressive craniectomy during follow-up but died 47 days after treatment.

The remaining 12 patients (3.1%) had non-neurological complications, including contrast-induced nephropathy (5 patients, 1.3%) and femoral artery thrombosis (2 patients, 0.5%). Detailed prolonged hospitalization and complication rates across the risk factor categories are given in the Table 3.

Table 3
Prolonged hospitalization and complication rates across the risk factor categories are given in tabular format

BMI > 30 vs. <30	**Prolonged Hospitalization Rate**	**30-day Complication Rate**	**Neurological Complication Rate**
	18.9% vs. 23.7% - p = 0.397	**9.5% vs. 10.3% - p = 1.0**	**4.2% vs. 4.8% - p = 1.0**
Pulmonary Disease (present vs. none)	16.7% vs. 23.1% - p = 0.529	8.3% vs. 10.3% - p = 1.0	2.8% vs. 4.9% - p = 1.0
HT/HL (present vs. none)	**26.4% vs. 14% - p = 0.008**	12.1% vs. 5.8% - p = 0.068	**6.0% vs. 1.6% - p = 0.044**
CAD/PAD (present vs. none)	**28.6% vs. 13.8% - p < 0.001**	11.9% vs. 7.6% - p = 0.229	5.7% vs. 3.2% - p = 0.328
Age (> 80 vs. <80 years)	28.6% vs. 21.0% - p = 0.171	13.0% vs. 9.4% - p = 0.397	7.8% vs. 3.9% - p = 0.221
DM/Liver Disease/Malignancy (present vs. none)	**33.3% vs. 16.3% - p < 0.001**	**16.4% vs. 6.5% - p = 0.003**	**7.8% vs. 2.9% - p = 0.042**
Serum Creatinine (> 1.2 mg/dL vs. <1.2 mg/dL)	**30.5% vs. 16.4% - p = 0.001**	**17.5% vs. 4.6% - p < 0.001**	**9.0% vs. 1.4% - p < 0.001**
History of TIA/stroke (present vs. none)	23.6% vs. 20.3% - p = 0.515	10.3% vs. 9.8% - p = 0.513	5.3% vs. 3.3% - p = 0.447
Carotis Stenosis (> 80% vs. <80%)	22.9% vs. 21.7% - p = 0.892	10% vs. 10.4% - p = 1.0	4.6% vs. 4.7% - p = 1.0
Bilateral Carotis Stenosis > 70% (present vs. none)	24.3% vs. 21.2% - p = 0.540	11.9% vs. 8.8% - p = 0.313	4.7% vs. 4.6% - p = 1.0
Contrast media volume (> 150mL vs. <150mL)	42.9% vs. 21.8% - p = 0.096	21.4% vs. 9.7% - p = 0.160	7.1% vs. 4.6% - p = 0.494
Procedure Duration (> 40mins vs. <40mins)	43.8% vs. 21.6% - p = 0.060	18.8% vs. 9.8% - p = 0.214	6.3% vs. 4.6% - p = 0.541
Abnormal Carotis Plaque Morphology (present vs. none)	22.1% vs. 24.3% - p = 0.757	9.6% vs. 12.2% - p = 0.522	4.8% vs. 4.1% - p = 1.0

Analysis of the Risk Factors for Prolonged Hospitalization

In the analysis of pre-treatment and DSA-related risk factors, significantly higher rates of prolonged hospitalization were observed among patients with coronary/peripheral arterial disease (28.6% vs. 13.8%, $p < 0.001$), serum creatinine > 1.2 mg/dL (30.5% vs. 16.4%, $p = 0.001$), hypertension and/or hyperlipidemia (26.4% vs. 14.0%, $p = 0.008$), and diabetes mellitus, liver disease, and/or a history of malignancy (33.3% vs. 16.3%, $p < 0.001$).

Although similar trends were observed for age > 80 years (28.6% vs. 21.0%, p = 0.171), history of stroke/TIA (23.6% vs. 20.3%, p = 0.515), contrast volume > 150 mL (42.9% vs. 21.8%, p = 0.096), and procedure duration > 40 minutes (43.8% vs. 21.6%, p = 0.060), these differences did not reach statistical significance. No significant increase in prolonged hospitalization was observed in patients with BMI > 30 (p = 0.397), known lung disease (p = 0.529), stenosis > 80% (p = 0.892), bilateral carotid stenosis > 70% (p = 0.540), or abnormal plaque morphology and/or plaque length > 2 cm (p = 0.757).

In the multivariable binary logistic regression model constructed using the most significant pre-treatment and DSA-related predictors of prolonged hospitalization, coronary/peripheral arterial disease (p = 0.009), diabetes mellitus/liver disease and/or history of malignancy (p = 0.006), and serum creatinine > 1.2 mg/dL (p = 0.014) remained statistically significant in the final model. The model explained a modest proportion of variance (R^2=0.128, overall p < 0.001) (Table 4).

Table 4
Logistic regression model parameters and summary to predict prolonged hospitalization

Variables in the Equation					
	B	**S.E.**	**Wald**	**Sig.**	**Exp(B)**
High Creatinine	0.286	0.130	4.830	0.028	1.331
DM/Liver Disease/Malignancy	0.396	0.130	9.287	0.002	1.485
CAD/PAD	0.823	0.286	8.275	0.004	2.278
Contrast Agent>150mL	1.362	0.600	5.144	0.023	3.903
Model Summary					
-2 Log likelihood		**Cox & Snell R Square**		**Nagelkerke R Square**	
378.245		0.084		0.128	

In ROC analysis of the proposed scoring system for prolonged hospitalization, the AUC was 0.647 (95% CI, 0.583–0.712; p < 0.001) and significantly greater than 0.5. The optimal cut-off value (highest Youden's J) was 8.5, yielding 58.6% sensitivity and 61.9% specificity (30.9% PPV and 83.7% NPV). A more compact scoring system using only the four significant factors with the same weights yielded an AUC of 0.681 (95% CI, 0.619–0.743; p < 0.001). Finally, ROC analysis of the predicted probabilities from the regression model showed an AUC of 0.692 (95% CI, 0.630–0.754; p < 0.001). For the compact score, the cut-off was 2.5 and had sensitivity and specificity of 64.4% and 60.0%, (31.9% PPV and 85.3% NPV) respectively; for the regression model, they were 60.9% and 66.2% (34.4% PPV and 85.3% NPV), respectively. Comparisons of AUC values showed no statistically significant differences among the proposed scoring system, the compact scoring system, and the regression model (Fig. 1).

Analysis of Risk Factors for 30-Day Complications

In the analysis of pre-treatment and DSA-related risk factors, significantly higher 30-day complication rates were observed in patients with diabetes mellitus, liver disease, and/or a history of malignancy (16.4% vs. 6.5%, p = 0.003) and serum creatinine > 1.2 mg/dL (17.5% vs. 4.6%, p < 0.001).

Although similar trends were observed for hypertension and/or hyperlipidemia (12.1% vs. 5.8%, p = 0.068), coronary/peripheral arterial disease (11.9% vs. 7.6%, p = 0.229), age > 80 years (13.0% vs. 9.4%, p = 0.397), history of stroke/TIA (10.3% vs. 9.8%, p = 0.513), contrast volume > 150 mL (21.4% vs. 9.7%, p = 0.160), procedure duration > 40 minutes (18.8% vs. 9.8%, p = 0.214), and bilateral carotid artery stenosis > 70% (11.9% vs. 8.8%, p = 0.313), these differences did not reach statistical significance. No significant increase in 30-day complication rates was observed in patients with BMI > 30 (p = 1.0), known lung disease (p = 1.0), stenosis > 80% (p = 1.0), or abnormal plaque morphology and/or plaque length > 2 cm (p = 0.522).

In the multivariable binary logistic regression model constructed using the four most significant pre-treatment and DSA-related predictors, diabetes mellitus/liver disease and/or history of malignancy (p = 0.022) and serum creatinine > 1.2 mg/dL (p < 0.001) remained statistically significant in the final model. The model had an R^2 of 0.132 (overall p < 0.001) (Table 5).

Table 5
Logistic regression model parameters and summary to predict 30-day complications.

Variables in the Equation					
	B	**S.E.**	**Wald**	**Sig.**	**Exp(B)**
High Creatinine	-1.324	0.394	11.321	0.001	0.266
DM/Liver Disease/Malignancy	-0.822	0.359	5.241	0.022	0.440
CAD/PAD	-0.231	0.383	0.362	0.547	0.794
Contrast Agent>150mL	-1.152	0.720	2.556	0.110	0.316
Model Summary					
-2 Log likelihood		**Cox & Snell R Square**		**Nagelkerke R Square**	
227,308		0.063		0.132	

In ROC analysis of the proposed scoring system for 30-day complications, the AUC was 0.651 (95% CI, 0.553–0.749; p = 0.003). The optimal cut-off value (highest Youden's J) for predicting 30-day complications was 10.5, yielding 38.5% sensitivity and 86.1% specificity (PPV: 23.7%, NPV: 92.6%). The compact four-parameter scoring system demonstrated improved discrimination, with an AUC of 0.721 (95% CI, 0.636–0.805; p < 0.001). The optimal cut-off for the compact score was 3.5, with 51.3% sensitivity and 82.1% specificity (PPV: 24.4%, NPV: 93.8%). ROC analysis of the predicted probabilities from the regression model yielded an AUC of 0.730 (95% CI, 0.642–0.817; p < 0.001), with 71.8% sensitivity and 68.5% specificity (PPV: 20.2%, NPV: 95.6%) (Fig. 2).

In comparisons of AUC values, both the compact scoring system (p = 0.032) and the regression model (p = 0.012) had significantly higher AUCs than the proposed scoring system.

Analysis of the Risk Factors for Neurological Complications

In the analysis of pre-treatment and DSA-related risk factors, significantly higher neurological complication rates were observed in patients with hypertension and/or hyperlipidemia (6.0% vs. 1.6%, p = 0.044), diabetes mellitus, liver disease, and/or a history of malignancy (7.8% vs. 2.9%, p = 0.042), and serum creatinine > 1.2 mg/dL (9.0% vs. 1.4%, p < 0.001).

Although similar trends were observed for coronary/peripheral arterial disease (5.7% vs. 3.2%, p = 0.328), age > 80 years (7.8% vs. 3.9%, p = 0.221), history of stroke/TIA (5.3% vs. 3.3%, p = 0.447), contrast volume > 150 mL (7.1% vs. 4.6%, p = 0.494), procedure duration > 40 minutes (6.3% vs. 4.6%, p = 0.541), and bilateral carotid artery stenosis > 70% (4.7% vs. 4.6%, p = 1.0), these differences did not reach statistical significance. No significant increase in neurological complication rates was observed in patients with BMI > 30 (p = 1.0), known lung disease (p = 1.0), stenosis > 80% (p = 1.0), or abnormal plaque morphology and/or plaque length > 2 cm (p = 1.0).

In the multivariable binary logistic regression model constructed using the four most significant pre-treatment and DSA-related predictors, serum creatinine > 1.2 mg/dL remained statistically significant in the final model (p = 0.006). The model had an R^2 of 0.128 (overall p = 0.003) (Table 6).

Table 6
Logistic regression model parameters and summary to predict neurological complications.

Variables in the Equation					
	B	**S.E.**	**Wald**	**Sig.**	**Exp(B)**
High Creatinine	-1.781	0.652	7.462	0.006	0.169
DM/Liver Disease/Malignancy	-0.750	0.510	2.162	0.141	0.472
CAD/PAD	-0.306	0.553	0.305	0.581	0.737
Contrast Agent>150mL	-0.640	1.106	0.334	0.563	0.528
Model Summary					
-2 Log likelihood		**Cox & Snell R Square**		**Nagelkerke R Square**	
129,718		0.040		0.128	

In ROC analysis of the proposed scoring system for neurological complications, the AUC was 0.708 (95% CI, 0.579–0.838; p = 0.002). The optimal cut-off value (highest Youden's J) was 8.5, yielding 72.2% sensitivity and 58.7% specificity (PPV: 7.9%, NPV: 97.7%). The compact four-parameter scoring system demonstrated an AUC of 0.738 (95% CI, 0.608–0.868; p < 0.001). The optimal cut-off for the compact

score was 3.5, with 61.1% sensitivity and 80.4% specificity (PPV: 13.3%, NPV: 97.7%). ROC analysis of the regression model output yielded an AUC of 0.753 (95% CI, 0.625–0.882; $p < 0.001$), with 77.8% sensitivity and 66.8% specificity (PPV: 10.2%, NPV: 98.4%). Comparisons of AUC values showed no statistically significant differences among the proposed scoring system, the compact scoring system, and the regression model (Fig. 3).

Discussion

Prolonged hospitalization represents a significant challenge for the healthcare system, primarily due to the associated unexpected and often avoidable costs. These consequences extend beyond institutional burdens, affecting patients and their families as well. In this preliminary study, we analyzed our data to identify complications related to carotid artery stenting that resulted in prolonged hospitalization, whether neurological or otherwise.

Clinical guidelines have been established to estimate risks associated with various treatments and patient management strategies. Risk estimates are consistently higher in symptomatic patients compared to asymptomatic individuals undergoing carotid interventions (11). According to the European Stroke Guidelines, the incidence of neurological complications can double in symptomatic patients receiving a carotid stent (17). In our cohort, 263 patients (68.1%) were symptomatic and 14 (5.3%) of which experienced neurologic complications compared to 4 patients in asymptomatic group (3.3%), a finding that aligns with the existing literature.

Yadav et al. reported that high-risk patients undergoing carotid stenting face a 12.2% risk of all-cause stroke and death, including a 6.1% risk of fatal or disabling stroke. Additionally, myocardial infarction may occur in up to 2.7% of cases (18). Gray et al. noted that the 30-day mortality rate following carotid stenting ranges from 0% to 1.1% (19–21). Hypotension is another potential complication, observed in approximately 3%–4% of carotid stenting procedures and known to contribute to extended hospital stays (22–25). In our series of 386 patients, four patients (1.04%) died within 30 days of the procedure—caused by stroke (0.26%), hyponatremia-septic shock (0.26%), post-operative acute coronary syndrome (0.26%), and bilateral widespread hemispheric ischemia (0.2%). Our rates of hypotension and myocardial infarction were both lower than those previously reported (0.35%). Furthermore, we conducted a detailed analysis of all complications within 30 days post-stenting, which included 18 neurological, 9 transient ischemic symptoms and 12 non-neurological events. Notably, we observed 5 cases of contrast-induced nephropathy (1.3%), two cases of pneumonia (0.35%), one case each of chronic mesenteric ischemia, hyponatremia, and femoral thrombosis requiring surgical intervention (0.52%). These specific complication rates have not been previously reported in the literature.

Several risk scoring systems—including the American Society of Anesthesiologists (ASA) classification, the Charlson Comorbidity Index, the Elixhauser Comorbidity Index, and the Siena Risk Scoring System—have been developed to identify both patient- and procedure-related risk factors to improve clinical outcomes (12, 26–28). In 2020, Goland et al. demonstrated the feasibility of outpatient craniotomy under

general anesthesia with a 100% success rate (29), while other studies have reported success rates ranging from 93% to 97% for similar procedures (9). In our study, we recorded 39 complications (10.1%), of which 31 (79.5%) occurred in patients classified as moderate- or high-risk. Additionally, 87 patients (22.5%) required prolonged hospitalization—a finding consistent with data from other medical specialties.

Modern predictive tools are increasingly used in clinical practice to estimate mortality, morbidity, risk of prolonged hospitalization, and other adverse outcomes (3, 30). Patients identified as moderate- or high-risk are more likely to experience such outcomes, prompting clinicians to carefully tailor therapy to minimize complications. Previous studies by Entezami and Goldmacher have demonstrated that major surgical and interventional procedures can be safely and successfully performed in carefully selected low-risk patients (8, 9). In our study, patients with scores < 9 (< 4 for the compact scoring) were considered low-risk. These individuals shown to have less complications and they experienced a trend to be treated successfully without requiring extended hospitalizations, leading to both cost savings and improved quality of care.

Moreover, our proposed scoring system can predict major complications such as significant neurological events that result in long-term sequelae or death; besides the more sophisticated compact system can predict this with lower sensitivity (72.2% vs. 61.1%) and better specificity values (80.4%). Patients with scores ≥ 9/≥4(compact) demonstrated a neurological complication rate of 7.9%-13.3% compared to 2.3% in those with lower scores, representing a 5.6% absolute risk increase and an approximately 3.4-fold relative risk elevation, findings that support the clinical relevance of the proposed threshold. However, a score < 9 or < 4 does not fully exclude the probable risk of events within 30 days. The scoring model developed by Setacci et al., later validated by Zhou et al., demonstrated that neurological events and mortality could be predicted with 74.3%–77% accuracy (12, 16). While these systems did not address prolonged hospitalization, our model incorporates similar variables and demonstrates potential in predicting extended hospital stays. Using the cutoff score ≥ 9, the original model identified patients at increased risk for prolonged hospitalization, with event rates of 30.9% compared to 16.3% in the low-score group. The compact simplified scoring system achieved even greater risk separation at a cutoff score ≥ 4 (34.4% vs. 14.7%), corresponding to a 19.7% absolute risk difference and an approximately 2.3-fold relative increase. This enhanced risk enrichment, combined with preserved negative predictive performance, supports the potential clinical utility of the compact model for pragmatic risk stratification in routine practice.

Risk stratification is essential for guiding patient selection and enabling informed consent discussions. Octogenarians are particularly vulnerable, with higher complication rates following carotid stenting compared to younger patients (12–16, 32). The risk is further elevated in symptomatic patients and those with severe contralateral internal carotid artery (ICA) stenosis (12, 16). In our study, patients requiring prolonged hospitalization had a higher mean age and symptomatic prior to CAS, but we were unable to show the same trends for the patients with higher ipsilateral stenosis (> 80%) and bilateral carotid stenosis. These findings are in line with the established role of age and symptomatic status in

adverse outcomes, whereas the lack of association with stenosis severity may reflect sample size limitations or population-specific characteristics.

Before a scoring system can be widely adopted in clinical practice, its reliability must be validated in large, diverse cohorts by multiple practitioners. Typically, such validation is performed using Receiver Operating Characteristic (ROC) curve analysis and Chi-square testing. Variables commonly used in predictive models include advanced age (≥ 80 years), malignancies, diabetes mellitus, elevated serum creatinine, and other chronic conditions (2–4, 12, 16). Gokhale et al. reviewed models predicting prolonged hospitalization and reported accuracies ranging from 65% to 94% (3). In our study, a cutoff value of ≥ 9 in the original model and ≥ 3 in the compact model predicted prolonged hospitalization with sensitivities up to 64.4% and specificities up to 61.9%. Besides; thresholds of ≥ 9 and ≥ 4, respectively, achieved sensitivities up to 72.2% and specificities up to 80.4% for neurologic complications.

This study has several limitations. First, it is a preliminary, single-center analysis involving low patient numbers having all-cause complications from a larger cohort of patients undergoing carotid stenting. Second, the scoring system we propose has not yet been externally validated, which may raise concerns among readers. Third, the parameters included in our model may not have fully capture all possible related risk factors in clinical setting. Nonetheless, this study is unique in its inclusion of both neurological and non-neurological complications. With this initial data, a more comprehensive multi-center analysis—or a prospective, randomized trial—may help refine the scoring system and optimize clinical care by enhancing quality and reducing healthcare costs.

In conclusion, our proposed scoring system shows promise in identifying patients with higher risks of complications and prolonged hospitalization in the context of carotid angioplasty and stenting. While further validation is necessary, it may serve as a useful tool to improve clinical decision-making and ultimately enhance the quality of care

Declarations

Acknowledgments:

None

Conflict of Interest:

None to declare

Ethics Declaration:

We declare that this study has been approved by the Ankara University Clinical Research Ethics Board on January 14th, 2025 (I11-888-24) and has therefore been performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki and its later amendments. We declare that all patients gave informed consent prior to inclusion in this study.

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Available if needed.

References

1. Doctoroff L, Shoshana J. Herzig. Predicting patients at risk for prolonged hospital stays. Med Care. 2020;58(9):778–84.
2. O'Sullivan, Kim, et al. Epidemiology of long-stay patients in a university teaching hospital. Intern Med J. 2017;47(5):513–21.
3. Gokhale S, et al. Hospital length of stay prediction tools for all hospital admissions and general medicine populations: systematic review and meta-analysis. Front Med. 2023;10:1192969.
4. Liu J, et al. Comparison of measures to predict mortality and length of stay in hospitalized patients. Nurs Res. 2019;68(3):200–9.
5. Aridi HD, et al. Predictors of prolonged length of stay after elective carotid revascularization. J Vasc Surg. 2024;80(4):1120–30.
6. Aberle S, et al. Outpatient Yttrium-90 microsphere radioembolization: Assessment of radiation safety and quantification of post-treatment adverse events causing hospitalization. Radiol Med. 2020;125:971–80.
7. Lo T-C, et al. Outpatient percutaneous endovascular abdominal aortic aneurysm repair: a single-center experience. J Vasc Interv Radiol. 2021;32(3):466–71.
8. Entezami P, et al. Developing a fast-track discharge protocol for patients with cerebral aneurysms treated via neuroendovascular techniques. Interventional Neuroradiol. 2024;30(2):163–9.
9. Goldmacher J, Bernstein M, Lashmi Venkatraghavan. Same day discharge for craniotomy. Curr Opin Anesthesiology. 2021;34(5):569–74.
10. Trunfio T, Angela A, Borrelli, Improta G. Implementation of Predictive Algorithms for the Study of the Endarterectomy LOS. *Bioengineering* 9.10 (2022): 546.
11. Spiliopoulos S, et al. CIRSE standards of practice on carotid artery stenting. Cardiovasc Interv Radiol. 2024;47(6):705–16.
12. Setacci C et al. Siena carotid artery stenting score: a risk modelling study for individual patients. *Stroke* 41.6 (2010): 1259–1265.
13. Roubin GS, et al. Immediate and late clinical outcomes of carotid artery stenting in patients with symptomatic and asymptomatic carotid artery stenosis: a 5-year prospective analysis. Circulation. 2001;103(4):532–7.

14. Cheng C-A, et al. Risk analysis of carotid stent from a population-based database in Taiwan. Medicine. 2016;95:e4747.
15. Çelebioğlu E, Can et al. Carotid artery stenting for symptomatic carotid near occlusions: Feasibility, safety and outcome analysis. Interventional Neuroradiol (2024): 15910199241292387.
16. Zhou H, et al. Predicting the risk of stroke in Chinese internal carotid artery stenosis patients underwent carotid artery stenting: validation and improvement of siena carotid artery stenting risk score. J Stroke Cerebrovasc Dis. 2019;28:104369.
17. Liapis CD, et al. ESVS guidelines. Invasive treatment for carotid stenosis: indications, techniques. Eur J Vasc Endovasc Surg. 2009;37(4):1–19.
18. Yadav JS, et al. Protected carotid-artery stenting versus endarterectomy in high-risk patients. N Engl J Med. 2004;351:1493–501.
19. Gray WA, et al. Influence of site and operator characteristics on carotid artery stent outcomes: analysis of the CAPTURE 2 (Carotid ACCULINK/ACCUNET Post Approval Trial to Uncover Rare Events) clinical study. JACC: Cardiovasc Interventions. 2011;4(2):235–46.
20. Gray WA, Chaturvedi S, Verta P. Thirty-day outcomes for carotid artery stenting in 6320 patients from 2 prospective, multicenter, high-surgical-risk registries. Circulation: Cardiovasc Interventions. 2009;2(3):159–66.
21. Hobson II, Robert W, et al. Carotid artery stenting is associated with increased complications in octogenarians: 30-day stroke and death rates in the CREST lead-in phase. J Vasc Surg. 2004;40(6):1106–11.
22. Park B, et al. Carotid artery angioplasty with stenting and postprocedure hypotension. Am J Surg. 2005;190:691–5.
23. Trocciola SM, et al. Analysis of parameters associated with hypotension requiring vasopressor support after carotid angioplasty and stenting. J Vasc Surg. 2006;43(4):714–20.
24. Mylonas SN, et al. Carotid artery stenting–induced hemodynamic instability. J Endovasc Ther. 2013;20(1):48–60.
25. Yang X, et al. Incidence and risk factors for hypotension after carotid artery stenting: Systematic review and meta-analysis. Int J Stroke. 2024;19(1):40–9.
26. Saklad M. Grading of patients for surgical procedure. *Anesthesiology* 2 (1941): 281–284.
27. Charlson ME, et al. Charlson comorbidity index: a critical review of clinimetric properties. Psychother Psychosom. 2022;91(1):8–35.
28. Moore BJ, et al. Identifying increased risk of readmission and in-hospital mortality using hospital administrative data: the AHRQ Elixhauser Comorbidity Index. Med Care. 2017;55(7):698–705.
29. Goland J, et al. Outpatient treatment of cerebral aneurysms: a case series. Surg Neurol Int. 2020;11:400.
30. Mehaffey JH, et al. Modifiable factors leading to increased length of stay after carotid endarterectomy. Ann Vasc Surg. 2017;39:195–203.

31. Hilton C, Beau, et al. Personalized predictions of patient outcomes during and after hospitalization using artificial intelligence. NPJ Digit Med. 2020;3(1):51.
32. Stanziale SF, et al. Carotid artery stenting in octogenarians is associated with increased adverse outcomes. J Vasc Surg. 2006;43(2):297–304.

Figures

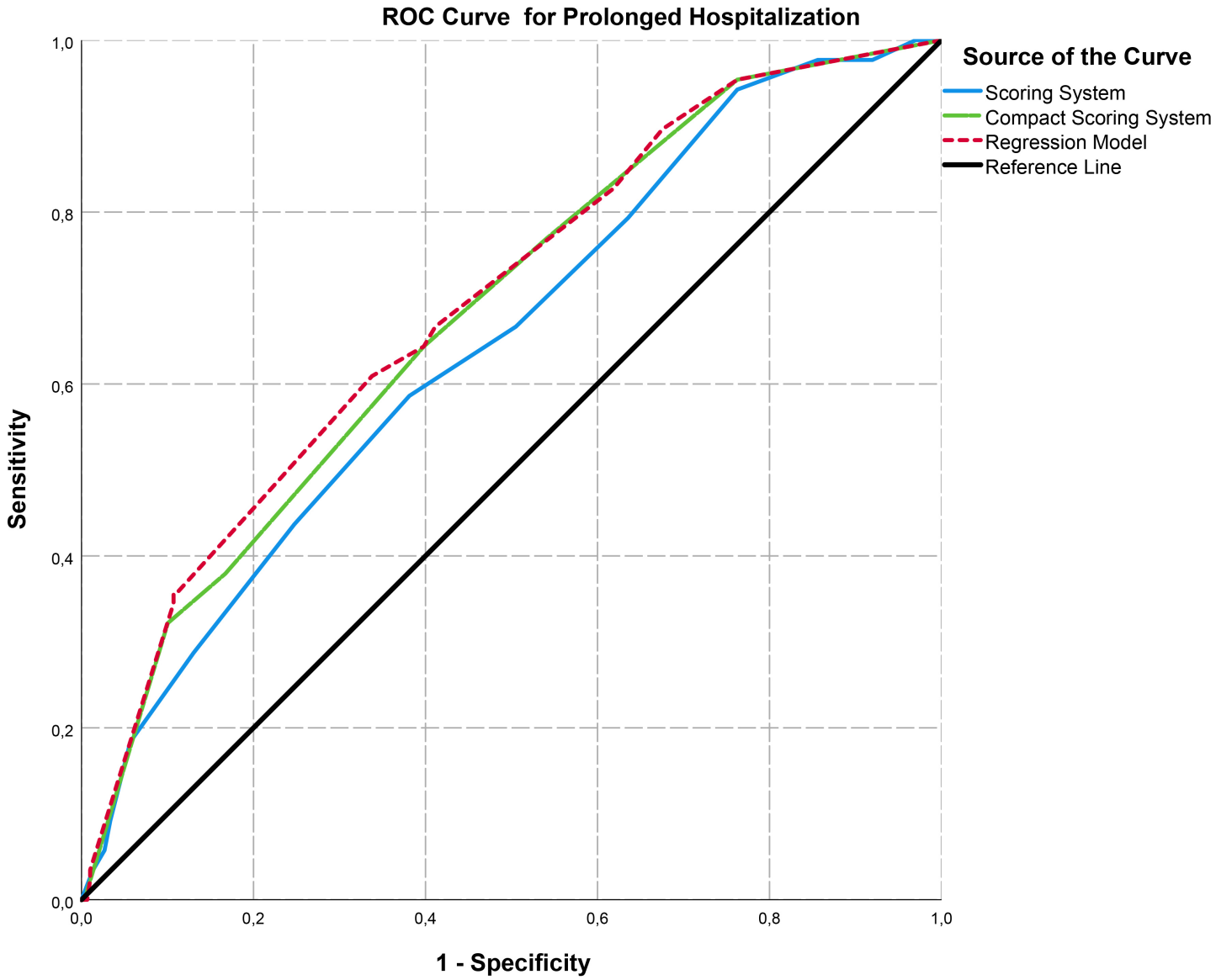


Figure 1

Comparative ROC analyses to predict prolonged hospitalization with the proposed models and regression analyses.

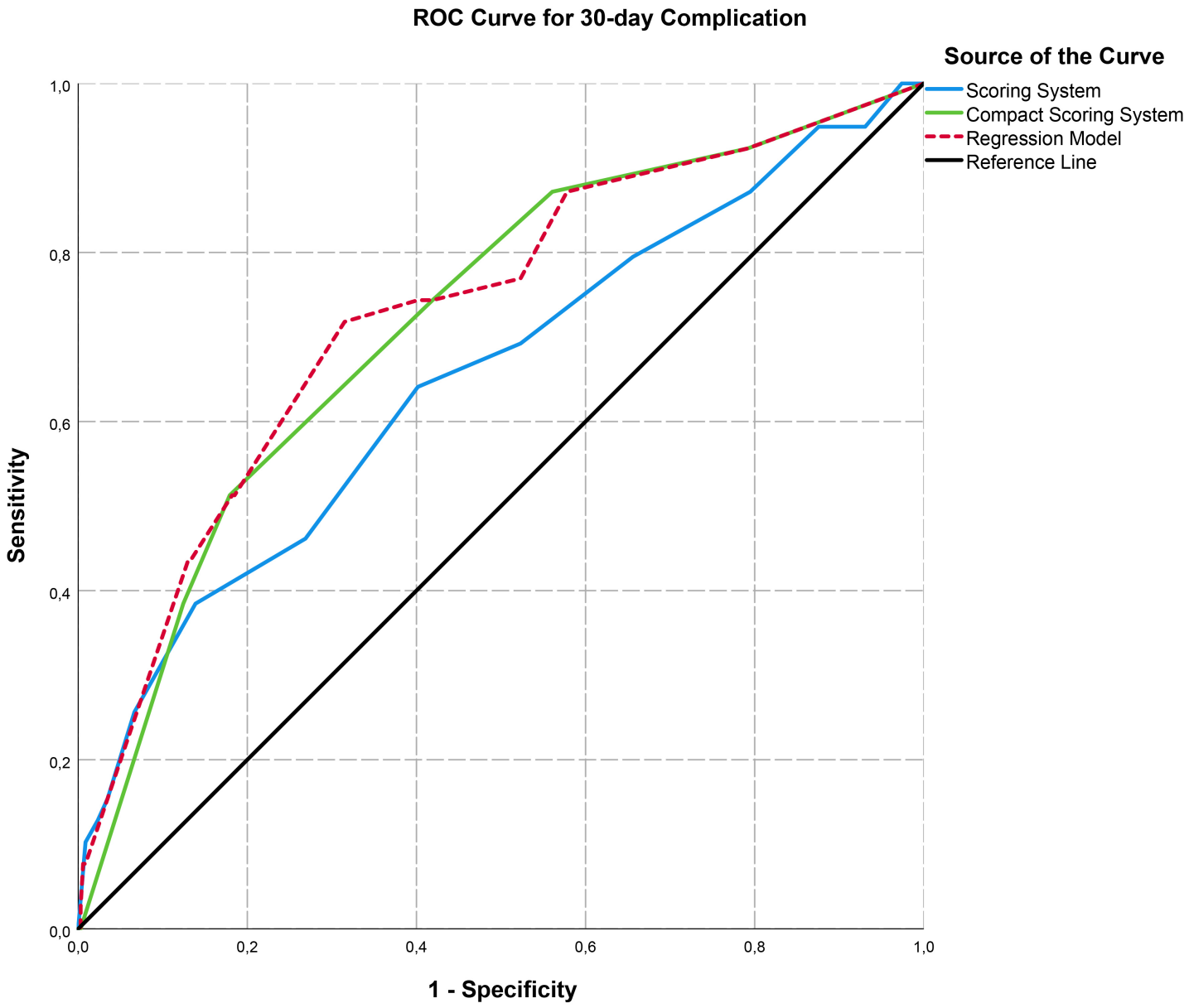


Figure 2

Comparative ROC analyses to predict 30-day complications with the proposed models and regression analyses.

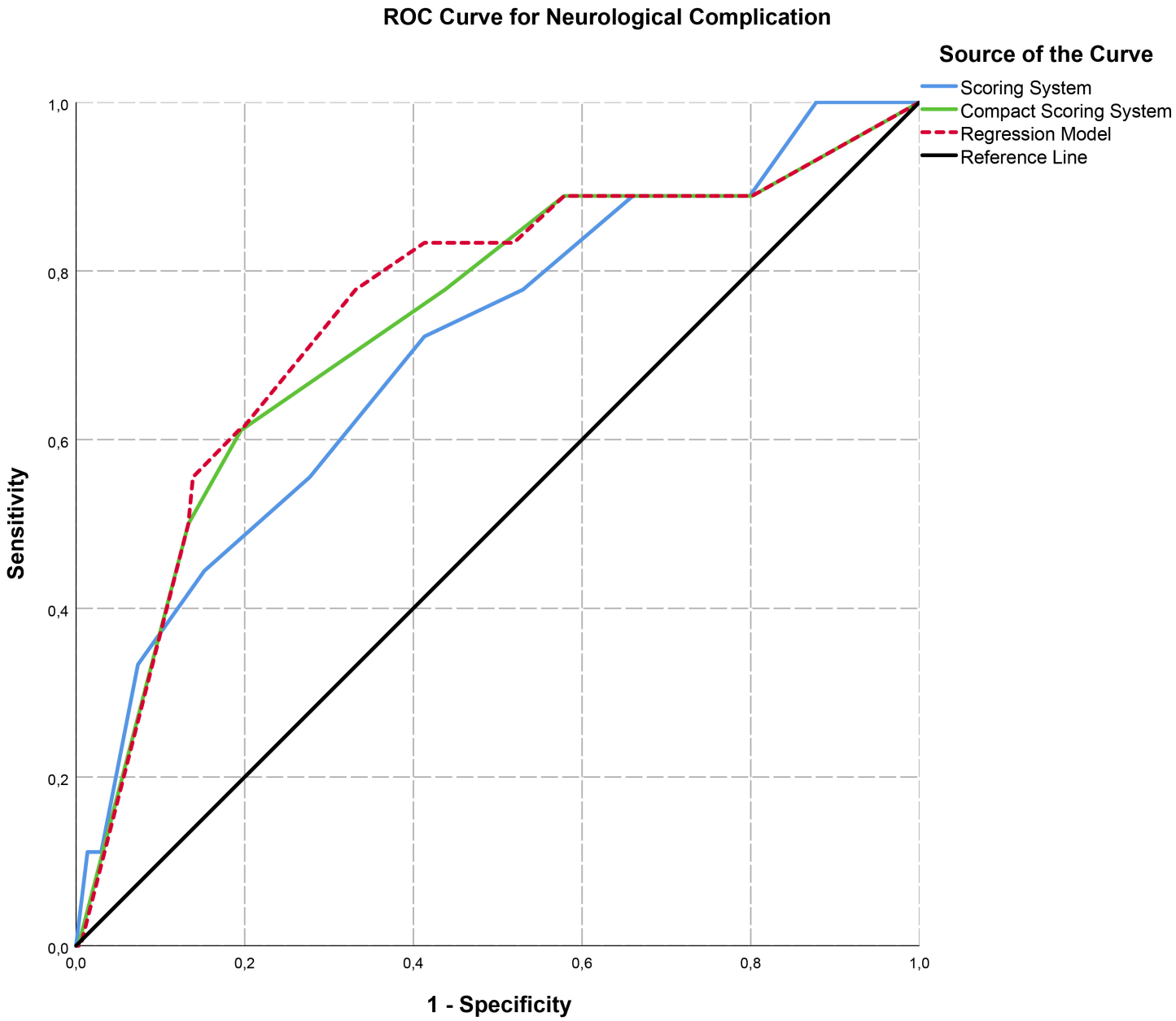


Figure 3

Comparative ROC analyses to predict neurological complications with the proposed models and regression analyses.