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ORIGINAL RESEARCH

# Accuracy and Clinical Utility of Clinical Predictive Models for Identifying Dizziness with Central Causes; A Retrospective Diagnostic Accuracy Study

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**Abstract:** **Introduction:** Although several clinical prediction models (CPMs) have been developed for identifying acute dizziness with central causes, their application in clinical practice remains unclear. This study aimed to evaluate the accuracy and clinical utility of four CPMs in identifying dizziness with central lesions. **Methods:** This single-center, retrospective, diagnostic accuracy study was conducted at the ED of Aomori Hospital, Japan, from April to March 2023. The area under the receiver operating characteristic curve (AUROC) of four risk stratification models (ABCD2, TriAGe+, PCI, and Sudbury) in predicting dizziness with central causes were evaluated considering the brain imaging (computed tomography (CT) scan and magnetic resonance imaging (MRI)) findings, interpreted by a neurologist or neurosurgeon, as the gold standard. Calibration was evaluated visually using calibration plots. Additionally, analyses of efficacy, safety, and clinical utility using a decision curve were conducted. **Results:** Of the 3,606 patients identified, 2,958 with the mean age of 65.3 ± 16.4 (range: 15-97.) years were included in the final analysis (64.7% female). 155 (5.2 %) were diagnosed with central lesions. The AUROCs were 0.67 (95% confidence interval (CI): 0.62–0.71) for ABCD2, 0.80 (95% CI: 0.76–0.84) for TriAGe+, 0.82 (0.78-0.86) for PCI, and 0.85 (95% CI: 0.82–0.88) for Sudbury. TriAGe+, PCI, and Sudbury demonstrated good calibration. Among these, the Sudbury model demonstrated the highest diagnostic efficiency, was the only model to meet safety criteria, and provided the highest net benefit in decision curve analysis, particularly at lower predicted prevalence thresholds. **Conclusion:** The TriAGe+, PCI, and Sudbury models demonstrated strong discriminatory performance and reliable calibration when applied during ED admission at a community hospital. Particularly, the Sudbury model may reduce false-negative outcomes for central lesions, thereby potentially minimizing the need for unnecessary neuroimaging in patients identified as low-risk.

**Keywords:** Dizziness; Vertigo; Emergency Service, Hospital; Predictive Value of Tests; Clinical Decision Rules

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## 1. Introduction

Dizziness is a common symptom, accounting for 2.5–3% of emergency department (ED) visits, 3–10% of which are due to central lesions (1-5). Dizziness with central causes is associated with a higher mortality rate (3). The most common central cause is posterior cerebral circulation infarction of the cerebellum and brainstem, with up to 14.5% of cases missed at initial presentation (6).

The use of brain computed tomography (CT) scan in ED has increased. However, the unnecessary increase in CT scan utilization contributes to longer lengths of stay and higher medical costs (7, 8). Despite the increased use, the diagnostic rate for central dizziness has not improved considerably, as CT scans have been reported to exhibit low sensitivity (9). Moreover, emergency physicians may mistakenly rule out central causes of dizziness based solely on negative CT scan findings (10).

Magnetic resonance imaging (MRI), offers high sensitivity and is required for accurate diagnosis. However, owing to the cost and time constraints associated with MRI, it is not feasible to perform it on all patients presenting with dizziness.

Therefore, to optimize the use of CT scan and MRI for patients at high risk of central lesions, well-validated diagnostic prediction models are essential to help identify those at high risk. Over the past few decades, several clinical prediction models, such as ABCD2, TriAGe+, PCI, web calculator nomogram, and Sudbury Vertigo Risk score, have been developed to stratify the risk of central lesions in patients with dizziness (11-16). However, these models have not been widely adopted in routine clinical practice because it remains unclear whether they are useful in the ED setting and no large Asian validation of these scores has been conducted in an ED population. The ABCD2 score has shown low discrimination in external validation (11-13). The PCI risk score was developed in non-ED cohort. The models by Bi et al. (14) and by

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Han et al. (15) rely on predictors that are not routinely measured in the ED setting. The Sudbury Vertigo Risk Score was developed in the ED setting, but its development in a university hospital population raises concerns regarding its transportability to community hospital (16). Therefore, it is essential to externally validate and compare the diagnostic accuracies of the mentioned models in ED setting. This study aimed to evaluate the accuracy and clinical utility of these models in stratifying the dizziness cases with high risk of central causes.

## 2. Methods

### *2.1. Study design and setting*

This single-center, retrospective, diagnostic accuracy study was conducted at the ED of Aomori Prefectural Central Hospital, a regional tertiary care teaching hospital in Japan, from April to March 2023. The hospital also serves as a regional stroke center and is equipped to perform brain CT scan and MRI 24 hours a day. The area under the receiver operating characteristic curve (AUROC) of four risk stratification models (ABCD2, TriAGe+, PCI, and Sudbury) in predicting dizziness with central causes were evaluated considering the brain imaging (CT scan and MRI) findings as the gold standard.

A comparison between models is presented in supplementary table 1. A key difference in the data source settings is that the ABCD2 and Sudbury scores were developed in university hospital settings, whereas the PCI model was developed using data from inpatients in a neurology department. Regarding participant recruitment, the TriAGe+ and PCI groups included only patients who underwent MRIs. Differences in target conditions include the following: the ABCD2 and TriAGe+ models focus on cerebrovascular diseases broadly, whereas the PCI model is specifically restricted to ischemic cerebrovascular diseases of the posterior circulation.

This study was approved by the Ethics Committee of the Aomori Prefectural Central Hospital (approval number: R05-2-001). A summary of the study was posted on the hospital's website, along with information on the opt-out process, allowing eligible patients to withdraw from the registry at any time.

### *2.2. Participants*

Patients who presented to the ED with a chief complaint of dizziness, vertigo, unsteadiness, and imbalance, were enrolled. Patients with head trauma, age under 15 years, pregnancy, shock state, syncope, severe anemia (hemoglobin < 7 g/dl), hypoglycemia (serum glucose < 70 mg/dl), hypernatremia (serum sodium > 150 mmol/l), hyponatremia (serum sodium < 120 mmol/l), drug addiction, a subacute or chronic course (onset of illness more than two weeks prior), or prior diagnosis and referral for specialized medical treatment were excluded. All data were retrospectively collected from electronic medical records.

### *2.3. Data gathering*

We retrospectively collected the variables used in the diagnostic prediction models from electronic medical records. When neurological findings were evaluated by healthcare professionals, we used the findings assessed by nurses, initial residents, emergency physicians, and on-call non-specialists prior to consultation with a neurologist or neurosurgeon at the time of the emergency visit.

The included predictors were the variables of ABCD2 score (age, blood pressure, speech disturbance, unilateral weakness, diabetes) (11), TriAGe+ score (absence of trigger, male sex, atrial fibrillation, blood pressure, skew deviation, diplopia, ocular movement disturbances, unilateral facial sensory disturbances, dysphagia, hiccup, dysmetria, trunk ataxia, focal weakness, speech impairment, dizziness, no history of vertigo or dizziness or labyrinth or vestibular disease) (12), PCI risk score (blood pressure, diabetes, history of ischemic stroke, sensations of rotating or rocking, speech difficulty, tinnitus, limb sensory deficits, gait ataxia, and limb ataxia) (13), and Sudbury vertigo risk score (male sex, age, diabetes, hypertension, motor or sensory deficits, diplopia, dysarthria, dysphagia, dysmetria, ataxia, and a diagnosis of benign paroxysmal positional vertigo) (16).

If a predictor was not explicitly described in the electronic medical record, we inferred it as accurately as possible from other available clinical information.

In the ED, neurological examinations routinely included assessment of cranial nerves II, III, IV, V, VI, VII, VIII, IX, XI, and XII; motor weakness and sensory disturbance of the extremities; dysarthria; aphasia; dysphonia; and cerebellar ataxia. Cerebellar ataxia was evaluated using finger-to-nose testing (FNF), diadochokinesis (DDK), heel-to-shin (HS) or heel-to-pat test (HP), the Romberg test, and gait observation. Brainstem dysfunction was defined as the presence of at least one of cranial nerve abnormality and/or dysarthria. Cerebellar dysfunction was defined as dysarthria and/or at least one abnormal finding in FNF, DDK, HS/HP, or gait assessment.

Patients were included if the attending clinician recorded "dizziness" as the presenting symptom at the initial emergency department visit. This symptom category encompassed various dizziness subtypes, including rotational vertigo, disequilibrium or unsteadiness, and presyncope. Shunsuke Soma (first author) was responsible for data gathering.

### *2.4. Reference standard*

The target condition of this study was central lesions, defined as those identified on brain CT scan or MRI and determined by a neurologist or neurosurgeon to be the cause of dizziness. Neuroimaging such as brain CT scan and MRI were not performed for all patients but selectively based on clinical judgment. For patients discharged from the ED, their medical records were reviewed if they revisited within one week, regardless of whether neuroimaging had been performed and subsequent diagnoses were included.

### 2.5. Sample size estimation

The sample size included >100 cases with central lesions. Based on previous studies, it was estimated that 3–10% of patients presenting with dizziness have central nervous system lesions, requiring a total sample size of approximately 1,000–3,000 cases. Given that our hospital records include approximately 200–300 cases of dizziness annually, we set the data collection period to 10 years to achieve the necessary sample size.

### 2.6. Statistical analysis

For predictors in the ABCD2, TriAGe+, PCI, and Sudbury models with >5% missing data, a single imputation using the chained equations method was applied. This approach incorporated all available variables except the target condition. Sisk et al. suggested that single imputation may be a reasonable alternative to multiple imputation methods for handling missing data in predictive models and recommended excluding outcomes as explanatory variables from the imputation process (17).

Patient characteristics were summarized using descriptive statistics. Continuous variables were expressed as mean ± standard deviation or median with interquartile range (IQR), depending on their distribution. Categorical variables were presented as frequencies and percentages. The variables of scoring models, including ABCD2 (12), TriAGe+ (13), PCI (13), and Sudbury (16) were used to calculate the total score and logistic regression models were applied to estimate the predicted probability of central lesions. For the ABCD2 model (11), the predictor 'duration' was consistently assigned a score of 2, in accordance with the original study. The discriminatory performance of the existing models was assessed using the AUROC, and calibration was visually evaluated using calibration plots.

To evaluate the clinical utility of the diagnostic prediction models, we assumed a clinical scenario in which central lesions could be safely ruled out without neuroimaging, such as brain CT scan and/or MRI, if the predicted probability was below a certain cutoff value. We pre-specified the cutoff value to < 1% before analysis based on two considerations. First, prior diagnostic prediction model development studies have defined the low-risk group as having a predicted probability of 0–5.9% (11, 12, 16). Second, a survey of emergency physicians indicated that a diagnostic probability threshold of less than 0.25–1% was considered acceptable for discharging patients without neuroimaging (18). Additionally, we performed a sensitivity analysis using alternative cutoff values of 5% and 0.5%.

We compared the safety and efficiency of the diagnostic prediction model using the aforementioned cutoff values. Safety was defined as the proportion of patients with central lesions among those classified by the models as "central lesion can be excluded without neuroimaging" among all patients with dizziness. If the upper limit of the 95% confidence interval (CI) for this proportion was lower than the predefined cutoff, the model was considered safe (19). In contrast, efficiency was defined as the proportion of patients classified as "central lesion that could be excluded" among all patients with dizziness. The 95% CIs for safety and efficiency were calculated using the Wilson scoring method.

Additionally, decision curve analysis (DCA) was performed to compare the clinical utility of the diagnostic prediction models directly. DCA estimates the net benefit of each model across a range of cutoff probabilities relevant to clinical decision-making. All statistical analyses were performed using Stata version 18.0 (StataCorp LLC, College Station, TX, USA). $P < 0.05$ was considered statistically significant.

## 3. Results

### 3.1. Patients' characteristics

During the study period, 3,606 patients presented to the ED with dizziness as their chief complaint. After excluding 648 patients based on exclusion criteria, 2,958 participants were included in the analysis, of whom 155 (5.2 %) had central lesions (Figure 1, supplementary table 1). Central lesions included ischemic stroke (n = 91, 58.7%), hemorrhagic stroke (n = 45, 29.0%), brain tumors (n = 13, 8.4%), central nervous system (CNS) infection (n = 2, 1.3%), inflammatory disease (n = 1, 0.6%), and others (n= 3, 1.9%). Among non-central lesions, the most common cause was otolaryngological disease (n = 1,223, 43.6%), followed by cardiovascular disease (n = 191, 6.8%).

Patient characteristics are shown in table 1. Briefly, the mean age was 65.3 ± 16.4 (range: 15-97) years (64.7% female). Episodic-triggered symptoms were observed in 61.9% of patients, and nausea was the most common accompanying symptom, occurring in 64.9%. The most prevalent stroke risk factors were hypertension (47.3%), hyperlipidemia (26.9%), and diabetes (14.5%). A history of dizziness was reported by 31.7% of patients.

### 3.2. Predictive performance of studied models

The AUROC was 0.67 (95% CI: 0.62–0.71) for ABCD2, 0.80 (95% CI: 0.76–0.84) for TriAGe+, 0.82 (95% CI: 0.78–0.86) for PCI, and 0.85 (95% CI: 0.82–0.88) for Sudbury model (supplementary table 1, Figure 2). In the calibration plot, predicted and observed probabilities were generally consistent across all models, suggesting good calibration, except for the ABCD2 model (Figure 3). The prevalence of central lesions across the three models with good calibration, along with the sensitivity, specificity, likelihood ratios for each score, and the number of brain CT scan and MRI performed, are presented in table 2.

### 3.3. Clinical utility

We compared the clinical utility of three models, TriAGe+, PCI, and Sudbury, excluding the ABCD2 model due to its low discrimination and poor calibration. The safety and efficiency of the predictions at cutoff values of 0.5%, 1%, and 5%

are listed in Table 3. Only the Sudbury model met the safety criteria at 1% cutoff, with an efficiency of 26.8% (95% CI: 25.2–28.4). At the 5% cutoff, all three models met the safety criteria: 2.1% (95% CI: 1.6–2.7) for TriAGe+, 2.1% (95% CI: 1.6–2.7) for PCI, and 1.7% (95% CI: 1.2–2.4) for Sudbury. The corresponding efficiencies were 82.8% (95% CI: 81.4–84.1) for TriAGe+, 83.6% (95% CI: 81.9–85.2) for PCI, and 65.3% (95% CI: 63.6–67.0) for Sudbury. At the more conservative cutoff of 0.5%, none of the three models met the predefined safety criteria.

The DCA of the three models is shown in Figure 4. The Sudbury model demonstrated a higher net benefit in the lower range of predicted probabilities for central lesions, whereas the other two models overlapped with a reference line representing the testing of all cases, particularly when the predicted probability of a central lesion was <2%.

Sensitivity, specificity, and negative likelihood ratio for identifying central lesions in the low-risk group, defined as a predictive probability of <1%, were as follows:

TriAGe+ (score <4): 98.7% (95%CI; 95.4-99.8), 14.3%(95%CI; 13.0-15.6), and 0.09 (95%CI; 0.02-0.36); PCI (score <-2): 97.4% (95%CI; 93.5-99.3), 9.7% (95%CI; 8.6-10.9), and 0.27 (95%CI; 0.10-0.71); Sudbury (score <0): 100% (95%CI; 97.6-100), 19.5% (95%CI; 18.0-21.0), and 0.00 (95%CI; not available).

If the Sudbury model had been applied, none of the 18 cases of central lesions that were initially missed in the ED would have been classified as low-risk (predicted probability <1%) in the validation cohort (Table 4). In other words, these cases would not have been missed without neuroimaging studies if the Sudbury model had been actively used in clinical practice at the emergency departments.

## 4. Discussion

This study demonstrated that the TriAGe+, PCI, and Sudbury scores were effective models in terms of both discrimination and calibration for predicting the risk of central lesions in patients presenting to the ED with acute dizziness. When the threshold for clinically acceptable safety was defined as a predicted probability of <1% for central lesions, the Sudbury model demonstrated the highest efficiency and was the only model to meet the predefined safety criteria. DCA further revealed that the Sudbury model provided the highest net benefit in the lower range of predicted probabilities. Given its adequate safety, we believe that patients assigned to the low-risk group (predicted probability <1%) by the Sudbury model could potentially be excluded from subsequent neuroimaging to confirm central lesions. However, a separate prospective impact analysis is required to evaluate whether implementation of the Sudbury model can reliably prevent diagnostic errors and reduce unnecessary neuroimaging in clinical practice.

The proportion of central lesions in our validation cohort was 5%, which differed from that in some of the development cohorts. This discrepancy may be explained by a spectrum effect: the development cohorts included only patients who underwent MRI examinations, thereby enriching the prevalence of stroke (12). In contrast, the prevalence observed in our validation cohort was consistent with that reported among patients presenting with dizziness in emergency settings (1-5). Therefore, our validation cohort is likely generalizable to patients with dizziness presenting to community hospital emergency departments, where a comparable prevalence is typically observed.

Using diagnostic prediction models, such as the Sudbury score, can reduce unnecessary neuroimaging in patients with dizziness without compromising diagnostic safety. Most patients presenting to EDs with acute dizziness have benign and self-limiting conditions. Excessive use of neuroimaging contributes to increased medical costs, prolonged ED waiting times, and reduced overall efficiency. In our study, the majority of central lesions were ischemic strokes of the posterior circulation, consistent with previous reports. A systematic review reported that CT has a sensitivity of 28.5% and specificity of 98.9% for detecting strokes (9), indicating that CT is not suitable for exclusionary diagnostic purposes in the ERs. In addition, a Canadian retrospective cohort study using propensity score matching indicated that CT may provide excessive reassurance, potentially leading to missed diagnoses of strokes (10). Nevertheless, it is impractical to perform MRI for all patients presenting to the ED with acute dizziness. Therefore, emergency physicians should assess the risk of central dizziness on the basis of stroke risk factors and physical examination findings. However, comprehensive and precise neurological assessments, including vestibular examinations, are highly specialized and may be difficult for emergency physicians to perform consistently. This challenge has led to an overreliance on neuroimaging, potentially reducing the use of well-validated diagnostic prediction models, such as the Sudbury model. In our study, using a Sudbury score <0 to define low-risk patients, CT scans could have been omitted in 116 (22.4% of all neuroimaging performed) and MRI in 24 cases (9.4%), with none of them identified as false negatives.

Nevertheless, some emergency physicians may remain concerned about ruling out central lesions without performing neuroimaging. Previous studies have reported that MRI has a sensitivity of only 79.8%, with a negative likelihood ratio of 0.20 (9), with a particularly high false-negative rate for detecting ischemic stroke in the posterior circulation when performed within 48 h of symptom onset (6). In contrast, when applying a predictive probability threshold of <1%, the Sudbury model demonstrated a sensitivity of 100% and negative likelihood ratio of 0.00, indicating that it may be more effective than MRI for ruling out central lesions in ERs. In our validation cohort, 22 patients (0.7%) who were ultimately diagnosed with central lesions were initially misdiagnosed with peripheral dizziness in the ER. If the Sudbury model had been applied with a predicted probability threshold of 1%, none of these would have been misclassified into the low-risk group. The strength of this study lies in the fact that it

is the first to compare several existing diagnostic prediction models in an ED setting. Only the ABCD2 and TriAGe+ scores have been externally validated to date, and our results were broadly consistent (12, 13, 20). Thus, the first external validations of PCI and Sudbury in this study are also likely to be robust.

Future studies should conduct multicenter prospective validation using universal MRI protocols to confirm the generalizability of our findings. In addition, the incorporation of point-of-care vestibular testing should be evaluated, as this may help non-specialists more accurately diagnose benign paroxysmal positional vertigo (BPPV), which was an important feature of the Sudbury model.

## 5. Limitations

First, since the data collection was conducted retrospectively, the temporal sequence between the timing of the predictor assessment and clinical confirmation of the target condition was unclear. In some cases, a central lesion may have been identified on neuroimaging before the medical history was obtained, and a physical examination was performed. For example, predictors of BPPV in the Sudbury model may not have been determined before neuroimaging, potentially overestimating the model's performance. Second, this study has a potential risk of imaging bias and verification bias, as MRI was not uniformly performed for all patients but selectively according to clinical judgment. In mild cases, particularly those evaluated with CT alone, small posterior strokes might have been missed, and such patients could have been misclassified as non-central. To minimize this risk, we reviewed the medical records of patients who were discharged from the ED and revisited within one week, which enabled us to capture progressive cases presenting with new neurological deficits. Because our hospital is the only tertiary care center in the region, referral of such progressive cases to other facilities was rare. Although minor strokes that resolved spontaneously without leaving deficits could not be fully identified, such cases required no therapeutic intervention and would be unlikely to have substantially influenced the clinical implications of our findings. Third, since the data were extracted from electronic medical records, the accuracy of the information obtained remains uncertain. Fourth, this study was conducted at a single center in Japan. Therefore, the generalizability of the findings should be interpreted with caution.

## 6. Conclusions

The TriAGe+, PCI, and Sudbury models demonstrated strong discriminatory performance and reliable calibration when applied during ED admission at a community hospital. Particularly, the Sudbury model may reduce false-negative outcomes for central lesions, thereby potentially minimizing the need for unnecessary neuroimaging in patients identified as low-risk.

## 7. Declarations

### 7.1. Acknowledgments

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### 7.2. Conflicts of interest

None declared.

### 7.3. Financial disclosure

Research grant findings from the Aomori Prefectural Central Hospital.

### 7.4. Authors' contributions

Shunsuke Soma conceived, designed, and conducted the study, and drafted the manuscript. Katsunori Ito provided critical advice on the study design and overall direction. Tsukasa Kamitani supervised the study as the senior author and confirmed the accuracy of the manuscript and the study findings. All authors read and approved the final version of the manuscript.

### 7.5. Data availability

We confirm that the data used in this study are available from the corresponding author and will be shared upon reasonable request.

### 7.6. Using artificial intelligence chatbots

ChatGPT was used to refine English expressions and improve the clarity of the manuscript. It was not used for data processing, statistical analysis, or generating scientific content.

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**Table 1:** Characteristics of studied patients

| Characteristics | Total (n=2,958) | Site of lesion | |
|---|---|---|---|
| | | Non-central (n=2,803) | Central (n=155) |
| **Age (year)** | | | |
| Mean ± SD | 65.3 ± 16.4 | 65.1 ± 16.6 | 67.6 ± 12.3 |
| **Sex** | | | |
| Male | 1,045 (35.3) | 954 (34.0) | 91 (58.7) |
| Female | 1,913 (64.7) | 1,849 (66.0) | 64 (41.3) |
| **Symptom** | | | |
| Episodic (trigger) | 1,830 (61.9) | 1,783 (63.6) | 47 (30.3) |
| Spontaneous | 1,130 (38.2) | 1,021 (36.4) | 109 (70.3) |
| Dizziness | 1,492 (50.6) | 1,391 (49.6) | 106 (68.4) |
| Vertigo | 1,461 (49.4) | 1,412 (50.4) | 49 (31.6) |
| Tinnitus | 340 (11.5) | 329 (11.7) | 11 (7.1) |
| Nausea | 1,919 (64.9) | 1,813 (64.7) | 106 (68.4) |
| Pre-syncope | 199 (6.7) | 196 (7.0) | 3 (1.9) |
| Deafness | 343 (11.6) | 329 (11.7) | 14 (9.0) |
| **Comorbidity** | | | |
| Hypertension | 1.398 (47.3) | 1,313 (46.8) | 85 (54.8) |
| Hyperlipidemia | 795 (26.9) | 753 (26.9) | 42 (27.1) |
| Diabetes mellitus | 430 (14.5) | 394 (14.1) | 36 (23.2) |
| Atrial fibrillation | 170 (5.7) | 153 (5.5) | 17 (11.0) |
| Coagulation defect | 12 (0.4) | 12 (0.4) | 0 (0.0) |
| **Medical history** | | | |
| Stroke/TIA | 326 (11.0) | 291 (10.4) | 35 (22.6) |
| CAD | 185 (6.3) | 178 (6.4) | 7 (4.5) |
| Vestibular disease | 307 (10.4) | 299 (10.7) | 8 (5.2) |
| Dizziness | 938 (31.7) | 913 (32.6) | 25 (16.1) |
| Head/neck trauma | 6 (0.2) | 5 (0.2) | 1 (0.6) |

Data are presented as mean ± standard deviation (SD) or frequency (%). TIA: transient ischemic attack; CAD: coronary artery disease

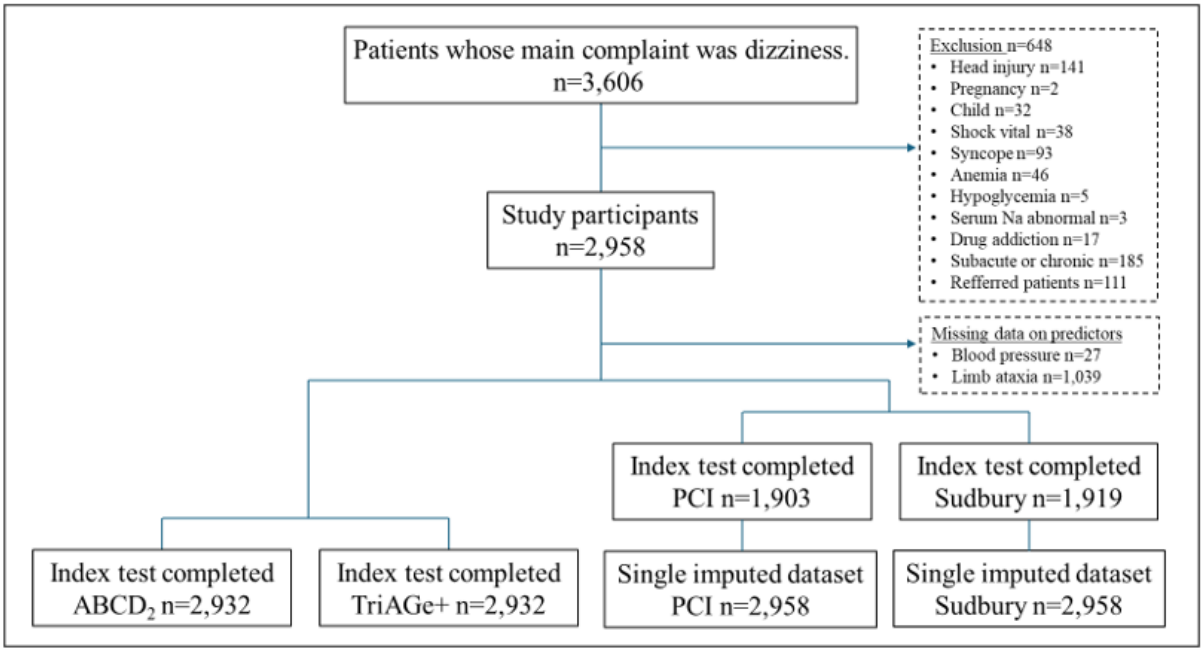


**Figure 1:** Flow diagram of patient selection and classification into central and non-central causes of dizziness in the emergency department.

**Table 2:** Diagnostic performance of risk scores with good calibration (TriAGe+, PCI, Sudbury)

| Score | n | Central lesion | | | | | Sensitivity | Specificity | LR+ | LR- | CT | MRI |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | total (%) | ischemic | hemorr-hage | tumor | other | | | | | | |
| **TriAGe+ score** | | | | | | | | | | | | |
| 0 | 54 | 0 (0) | 0 | 0 | 0 | 0 | 100 (NA) | 0 (NA) | 1.00 (NA) | NA | 25 | 2 |
| 1 | 20 | 0 (0) | 0 | 0 | 0 | 0 | 100 (97.6-100) | 1.9 (1.5-2.5) | 1.02 (1.01-1.03) | 0 (NA) | 11 | 0 |
| 2 | 325 | 2 (1) | 1 | 0 | 1 | 0 | 100 (97.6-100) | 2.7 (2.1-3.3) | 1.03 (1.02-1.03) | 0 (NA) | 193 | 9 |
| 3 | 187 | 4 (2) | 2 | 1 | 1 | 0 | 98.7 (95.4-99.8) | 14.3 (13.0-15.6) | 1.15 (1.12-1.18) | 0.09 (0.02-0.36) | 126 | 16 |
| 4 | 431 | 9 (2) | 5 | 2 | 2 | 0 | 96.1 (91.7-98.6) | 20.9 (19.4-22.4) | 1.21 (1.17-1.26) | 0.19 (0.08-0.41) | 297 | 25 |
| 5 | 459 | 8 (2) | 5 | 1 | 1 | 1 | 90.3 (84.4-94.4) | 36.1 (34.3-37.9) | 1.41 (1.33-1.50) | 0.27 (0.17-0.44) | 279 | 35 |
| 6 | 288 | 12 (4) | 8 | 4 | 0 | 0 | 85.1 (78.4-90.3) | 52.3 (50.4-54.2) | 1.78 (1.65-1.93) | 0.29 (0.20-0.42) | 201 | 40 |
| 7 | 460 | 11 (2) | 5 | 2 | 3 | 1 | 77.3 (69.8-83.6) | 62.2 (60.4-64.0) | 2.05 (1.86-2.26) | 0.37 (0.27-0.49) | 311 | 39 |
| 8 | 270 | 21 (8) | 13 | 6 | 1 | 1 | 70.1 (62.2-77.2) | 78.4 (76.8-79.9) | 3.25 (2.87-3.68) | 0.38 (0.30-0.49) | 180 | 30 |
| 9 | 215 | 24 (11) | 13 | 8 | 2 | 1 | 56.5 (48.3-64.5) | 87.4 (86.1-88.6) | 4.47 (3.77-5.30) | 0.50 (0.42-0.60) | 157 | 35 |
| 10 | 127 | 15 (12) | 11 | 2 | 1 | 1 | 40.9 (33.1-49.1) | 94.2 (93.3-95.1) | 7.10 (5.58-9.05) | 0.63 (0.55-0.72) | 104 | 26 |
| 11 | 39 | 15 (38) | 10 | 4 | 1 | 0 | 31.2 (24.0-39.1) | 98.3 (97.7-98.7) | 18.04 (12.51-26.00) | 0.70 (0.63-0.78) | 36 | 14 |
| 12 | 16 | 7 (44) | 4 | 3 | 0 | 0 | 21.4 (15.2-28.8) | 99.1 (98.7-99.4) | 24.80 (15.04-40.90) | 0.79 (0.73-0.86) | 15 | 6 |
| 13 | 16 | 8 (50) | 3 | 4 | 0 | 1 | 16.9 (11.3-23.8) | 99.5 (99.1-99.7) | 31.27 (16.91-57.80) | 0.84 (0.78-0.90) | 16 | 5 |
| 14 | 12 | 10 (83) | 4 | 6 | 0 | 0 | 11.7 (7.1-17.8) | 99.7 (99.5-99.9) | 46.39 (19.7-109.4) | 0.89 (0.84-0.94) | 12 | 4 |
| 15 | 11 | 7 (64) | 5 | 2 | 0 | 0 | 5.2 (2.3-10.0) | 99.8 (99.6-99.9) | 28.86 (9.55-87.19) | 0.95 (0.92-0.99) | 11 | 7 |
| 16 | 2 | 1 (50) | 1 | 0 | 0 | 0 | 0.6 (0.0-0.3) | 100 (99.8-100) | 18.04 (1.13-287.03) | 0.99 (0.98-1.01) | 2 | 2 |
| **PCI risk score** | | | | | | | | | | | | |
| -6 | 41 | 0 (0) | 0 | 0 | 0 | 0 | 100 (NA) | 0 | 1.00 (NA) | NA | 24 | 1 |
| -5 | 134 | 2 (1) | 2 | 0 | 0 | 0 | 100 (97.6-100) | 1.5 (1.1-2.0) | 1.01 (1.01-1.02) | 0.00 (NA) | 85 | 12 |
| -4 | 99 | 2 (2) | 2 | 0 | 0 | 0 | 98.7 (95.4-99.8) | 6.2 (5.4-7.2) | 1.05 (1.03-1.07) | 0.21 (0.05-0.83) | 76 | 11 |
| -3 | 26 | 2 (8) | 1 | 1 | 0 | 0 | 97.4 (93.5-99.3) | 9.7 (8.6-10.9) | 1.08 (1.05-1.11) | 0.27 (0.10-0.71) | 21 | 1 |
| -2 | 1 | 0 (0) | 0 | 0 | 0 | 0 | 96.1 (91.7-98.6) | 10.6 (9.5-11.8) | 1.07 (1.04-1.11) | 0.37 (0.17-0.81) | 1 | 0 |
| -1 | 265 | 0 (0) | 0 | 0 | 0 | 0 | 96.1 (91.7-98.6) | 10.6 (9.5-11.8) | 1.08 (1.04-1.11) | 0.37 (0.17-0.81) | 152 | 14 |
| 0 | 1,017 | 18 (2) | 10 | 0 | 6 | 2 | 96.1 (91.7-98.6) | 20.2 (18.7-21.7) | 1.20 (1.16-1.25) | 0.19 (0.09-0.42) | 651 | 62 |
| 1 | 844 | 26 (3) | 14 | 5 | 5 | 2 | 84.4 (77.7-89.8) | 56.1 (54.3-58.0) | 1.92 (1.78-2.08) | 0.28 (0.19-0.40) | 570 | 60 |
| 2 | 240 | 19 (8) | 14 | 4 | 1 | 0 | 67.5 (59.5-74.8) | 85.6 (84.2-86.9) | 4.68 (4.06-5.39) | 0.38 (0.30-0.48) | 173 | 41 |
| 3 | 35 | 11 (31) | 7 | 3 | 1 | 0 | 55.2 (47.0-63.2) | 93.5 (92.5-94.4) | 8.52 (6.97-10.41 | 0.48 (0.40-0.57) | 31 | 14 |
| 4 | 11 | 3 (27) | 2 | 1 | 0 | 0 | 48.1 (39.9-56.2) | 94.4 (93.5-95.2) | 8.56 (6.84-10.71) | 0.55 (0.47-0.64) | 11 | 2 |
| 5 | 51 | 1 (2) | 0 | 0 | 0 | 1 | 46.1 (38.1-54.3) | 94.7 (93.8-95.5) | 8.65 (6.86-10.91) | 0.57 (0.49-0.66) | 33 | 9 |
| 6 | 71 | 13 (18) | 7 | 6 | 0 | 0 | 45.5 (37.4-53.7) | 96.5 (95.7-97.1) | 12.88 (9.93-16.72) | 0.57 (0.49-0.65) | 60 | 26 |
| 7 | 55 | 31 (56) | 19 | 11 | 0 | 1 | 37.0 (29.4-45.2) | 98.6 (98.0-99.0) | 25.71 (17.75-37.22) | 0.64 (0.57-0.72) | 47 | 24 |
| 8 | 14 | 10 (71) | 4 | 6 | 0 | 0 | 16.9 (11.3-23.8) | 99.4 (99.1-99.7) | 29.31 (16.07-53.48) | 0.84 (0.78-0.90) | 13 | 4 |
| 9 | 4 | 4 (100) | 2 | 2 | 0 | 0 | 10.4 (6.1-16.3) | 99.6 (99.2-99.8) | 24.05 (11.58-49.94) | 0.90 (0.85-.0.95) | 4 | 2 |
| 10 | 2 | 1 (50) | 0 | 1 | 0 | 0 | 7.8 (4.1-13.2) | 99.6 (99.2-99.8) | 18.04 (8.24-39.49) | 0.93 (0.88-0.97) | 2 | 1 |
| 11 | 11 | 4 (36) | 4 | 0 | 0 | 0 | 7.1 (3.6-12.4) | 99.6 (99.3-99.8) | 18.04 (7.95-40.95) | 0.93 (0.89-0.97) | 11 | 6 |
| 12 | 8 | 6 (75) | 2 | 4 | 0 | 0 | 4.5 (1.8-9.1) | 99.9 (99.6-100) | 31.57 (9.34-106.68) | 0.96 (0.92-0.99) | 8 | 3 |
| 13 | 2 | 1 (50) | 0 | 1 | 0 | 0 | 0.6 (0.0-3.6) | 99.9 (99.7-100) | 9.02 (0.82-98.92) | 0.99 (0.98-1.01) | 2 | 1 |
| 14 | 1 | 0 (0) | 0 | 0 | 0 | 0 | 0.0 (0.0-2.4) | 100 (99.8-100) | 0.00 (NA) | 1.00 (1.00-1.00) | 1 | 1 |
| **Sudbury vertigo risk score** | | | | | | | | | | | | |
| -5 | 190 | 0 (0) | 0 | 0 | 0 | 0 | 100 (NA) | 0 (NA) | 1.00 (NA) | NA | 111 | 4 |
| -4 | 234 | 0 (0) | 0 | 0 | 0 | 0 | 100 (97.6-100) | 6.8 (5.9-7.8) | 1.07 (1.06-1.08) | 0.00 (NA) | 163 | 15 |
| -3 | 67 | 0 (0) | 0 | 0 | 0 | 0 | 100 (97.6-100) | 15.1 (13.8-16.5) | 1.18 (1.16-1.20) | 0.00 (NA) | 46 | 7 |

**Table 2:** Diagnostic performance of risk scores with good calibration (TriAGe+, PCI, Sudbury)

| Score | n | Central lesion | | | | | Sensitivity | Specificity | LR+ | LR- | CT | MRI |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | total (%) | ischemic | hemorr-hage | tumor | other | | | | | | |
| -2 | 55 | 0 (0) | 0 | 0 | 0 | 0 | 100 (97.6-100) | 17.5 (16.1-19.0) | 1.21 (1.19-1.23) | 0.00 (NA) | 43 | 3 |
| -1 | 246 | 0 (0) | 0 | 0 | 0 | 0 | 100 (97.6-100) | 19.5 (18.0-21.0) | 1.24 (1.22-1.26) | 0.00 (NA) | 191 | 13 |
| 0 | 446 | 4 (1) | 1 | 0 | 2 | 1 | 100 (97.6-100) | 28.3 (26.6-30.0) | 1.39 (1.36-1.43) | 0.00 (NA) | 251 | 16 |
| 1 | 438 | 17 (4) | 8 | 6 | 3 | 0 | 97.4 (93.5-99.3) | 44 (42.2-45.9) | 1.74 (1.67-1.81) | 0.06 (0.02-0.15) | 270 | 36 |
| 2 | 146 | 5 (3) | 3 | 0 | 2 | 0 | 86.5 (80.0-91.4) | 59 (57.2-60.9) | 2.11 (1.96-2.28) | 0.23 (0.15-0.34) | 86 | 12 |
| 3 | 111 | 7 (6) | 5 | 1 | 0 | 1 | 83.2 (76.4-88.7) | 64.1 (62.3-65.9) | 2.32 (2.13-2.53) | 0.26 (0.18-0.37) | 79 | 15 |
| 4 | 410 | 17 (4) | 10 | 3 | 3 | 1 | 78.7 (71.4-84.9) | 67.8 (66.0-69.5) | 2.44 (2.22-2.69) | 0.31 (0.23-0.43) | 274 | 36 |
| 5 | 295 | 14 (5) | 12 | 1 | 1 | 0 | 67.7 (59.8-75.0) | 81.8 (80.3-83.2) | 3.72 (3.26-4.26) | 0.39 (0.31-0.50) | 204 | 37 |
| 6 | 103 | 15 (15) | 8 | 5 | 0 | 2 | 58.7 (50.5-66.5) | 91.8 (90.8-92.8) | 7.19 (6.00-8.619 | 0.45 (0.37-0.54) | 77 | 23 |
| 7 | 47 | 13 (28) | 4 | 7 | 1 | 1 | 49 (40.9-57.2) | 95 (94.1-95.7) | 9.75 (7.77-12.23) | 0.54 (0.46-0.63) | 40 | 13 |
| 8 | 23 | 5 (22) | 2 | 3 | 0 | 0 | 40.6 (32.8-48.8) | 96.2 (95.4-96.9) | 10.65 (8.16-13.89) | 0.62 (0.54-0.70) | 20 | 5 |
| 9 | 26 | 6 (23) | 1 | 4 | 1 | 0 | 37.4 (29.8-45.5) | 96.8 (96.1-97.4) | 11.78 (8.83-15.73) | 0.65 (0.57-0.73) | 21 | 5 |
| 10 | 39 | 9 (23) | 7 | 2 | 0 | 0 | 33.5 (26.2-41.6) | 97.5 (96.9-98.1) | 13.63 (9.88-18.80) | 0.68 (0.61-0.76) | 35 | 12 |
| 11 | 35 | 15 (43) | 13 | 2 | 0 | 0 | 27.7 (20.9-35.5) | 98.6 (98.1-99.0) | 19.94 (13.34-29.81) | 0.73 (0.66-0.81) | 32 | 22 |
| 12 | 16 | 8 (50) | 3 | 5 | 0 | 0 | 18.1 (12.4-25.0) | 99.3 (98.9-99.6) | 26.65 (15.23-46.64) | 0.82 (0.77-0.89) | 12 | 3 |
| 13 | 8 | 5 (63) | 4 | 1 | 0 | 0 | 12.9 (8.1-19.2) | 99.6 (99.3-99.8) | 32.88 (16.04-67.40) | 0.87 (0.82-0.93) | 8 | 5 |
| 14 | 5 | 1 (20) | 1 | 0 | 0 | 0 | 9.7 (5.5-15.5) | 99.7 (99.4-99.9) | 33.91 (14.60-78.75) | 0.91 (0.86-0.95) | 5 | 3 |
| 15 | 9 | 8 (89) | 5 | 3 | 0 | 0 | 9 (5.0-14.7) | 99.9 (99.6-100) | 63.29 (21.1-190.02) | 0.91 (0.87-0.96) | 9 | 6 |
| 16 | 9 | 6 (67) | 4 | 2 | 0 | 0 | 3.9 (1.4-8.2) | 99.9 (99.7-100) | 36.17 (9.13-143.25) | 0.96 (0.93-0.99) | 8 | 5 |

Data are presented with 95% confidence interval. LR+: positive likelihood ratio; LR-: negative likelihood ratio; CT: computed tomography; MRI: magnetic resonance imaging; NA: not available.

**Table 3:** Safety and efficiency of three clinical prediction models with good calibration ((TriAGe+, PCI, Sudbury) at different cut-off points

| Cut-off point | Safety (95% CI) | Efficiency (95% CI) |
|---|---|---|
| **0.5%** | | |
| TriAGe+ score | 0.5 (0.1-1.8) | 13.6 (12.4-14.9) |
| PCI risk score | 2.0 (0.9-4.3) | 9.3 (8.3-10.5) |
| Sudbury Vertigo Risk score | 0.0 (0.0-0.8) | 16.6 (15.3-18.0) |
| **1%** | | |
| TriAGe+ score | 1.0 (0.5-2.2) | 20.0 (18.6-21.5) |
| PCI risk score | 2.0 (0.9-4.3) | 10.2 (9.2-11.4) |
| Sudbury Vertigo risk score | 0.0 (0.0-0.5) | 26.8 (25.2-28.4) |
| **5%** | | |
| TriAGe+ score | 2.1 (1.6-2.7) | 82.8 (81.4-84.1) |
| PCI risk score | 2.1 (1.6-2.7) | 83.6 (81.9-85.2) |
| Sudbury Vertigo Risk score | 1.7 (1.2-2.4) | 65.3 (63.6-67.0) |

Data are presented as %. CI: confidence interval.

**Table 4:** Scores and prediction probabilities of studied risk stratification models for cases with diagnostic errors

| Case | Diagnosis | TriAGe+ score | | PCI risk score | | Sudbury score | |
|---|---|---|---|---|---|---|---|
| | | Score | Prob (%) | Score | Prob (%) | Score | Prob (%) |
| 1 | Neuro-sarcoidosis | 8 | 7.5 | 0 | 2.6 | 3 | 4.2 |
| 2 | Metastatic Brain Tumor | 2 | 0.5 | 1 | 3.9 | 1 | 2.2 |
| 3 | Vertebrobasilar Insufficiency | 2 | 0.5 | 0 | 2.6 | 4 | 5.8 |
| 4 | Cerebellar Infarction | 10 | 17.2 | 2 | 6.0 | 3 | 4.2 |
| 5 | Vertebrobasilar Insufficiency | 5 | 2.0 | 0 | 2.6 | 2 | 3.1 |
| 6 | Transient Ischemic Attack | 5 | 2.0 | -4 | 0.4 | 1 | 2.2 |
| 7 | Cerebellar Infarction | 3 | 0.8 | -5 | 0.3 | 1 | 2.2 |
| 8 | Cerebellar Infarction | 10 | 17.2 | -3 | 0.7 | 5 | 7.8 |
| 9 | Bacterial Meningitis | 9 | 11.5 | 1 | 3.9 | 4 | 5.8 |
| 10 | Thalamic Hemorrhage | 5 | 2.0 | 1 | 3.9 | 4 | 5.8 |
| 11 | Vertebral Artery Dissection | 5 | 2.0 | 1 | 3.9 | 6 | 10.5 |
| 12 | Bridge Infarction | 6 | 3.1 | 0 | 2.6 | 8 | 18.4 |
| 13 | Thalamic Infarction | 9 | 11.5 | 4 | 13.3 | 6 | 10.5 |
| 14 | Acoustic Neuroma | 7 | 4.8 | 1 | 3.9 | 0 | 1.6 |
| 15 | Brainstem Infarction | 6 | 3.1 | -4 | 0.4 | 5 | 7.8 |
| 16 | Cerebellar Infarction | 11 | 24.9 | 7 | 36.7 | 11 | 37.6 |
| 17 | Cerebellar Infarction | 4 | 1.2 | 0 | 2.6 | 3 | 4.2 |
| 18 | Cerebellar Infarction | 7 | 4.8 | 6 | 27.2 | 7 | 14.0 |
| 19 | Cancerous Meningitis | 9 | 11.5 | 0 | 2.6 | 2 | 3.1 |
| 20 | Cerebellar Infarction | 7 | 4.8 | 0 | 2.6 | 4 | 5.8 |
| 21 | Transient Ischemic Attack | 10 | 17.2 | 2 | 6.0 | 5 | 7.8 |
| 22 | Vertebral Artery Dissection | 10 | 17.2 | 6 | 27.2 | 8 | 18.4 |

Prob: probability.

**Supplementary table 1:** Comparison of the characteristics of the present study and development cohorts for different studied

| Character | Present study (n=2,958) | Development studies | | | |
|---|---|---|---|---|---|
| | | ABCD2 (n=907) | TriAGe+ (n=498) | PCI (n=304) | Sudbury (n=2,078) |
| **Country** | Japan | USA | Japan | China | Canada |
| **Date** | Apr 2013–Mar 2023 | Jan 2007–Dec 2009 | Aug 2008–Sep 2013 | Jan 2010–Dec 2014 | Jul 2019–Aug 2022 |
| **Data source** | Retrospective, Single gate | Retrospective, Single gate | Retrospective, Single gate | Retrospective, Two gates | Prospective, Single gate |
| **Setting** | ED of teaching hospital | ED of university hospital | ED of community hospital | Hospitalization of Neurology | 3 EDs (university-affiliated) |
| **Inclusion criteria** | Symptoms related with dizziness | Symptoms related with dizziness | Symptoms related with dizziness | Case: Symptom related with dizziness; PCI confirmed*; Risk factors** >1 Control: Symptom related with dizziness; PCI denied*; Risk factors** >1 | Symptoms related with dizziness; Adults (>18y) |
| **Exclusion criteria** | Head injury; Pregnancy; Child (<15y); Shock; Syncope; Hb<7 g/dl; Glu<70 mg/dl; Na>150 mmol/l; Na<120 mmol/l; Subacute/chronic; Referred | Symptoms unrelated to dizziness; Faintness; Presyncope; Intestinal bleeding; Age<18y; No record of BP; MRI not performed | None | >14d since onset; Head/neck trauma (≤14d); GCS<15; SBP<90 mmHg; Syncope (≤14d); Active cancer | None |
| **Target condition (n, %)** | Central lesion (n=155, 5%) | Cerebrovascular event (n=37, 4%) | Stroke (n=147, 30%) | Posterior circulation ischemia (n=152, NA) | Stroke; Transient ischemic attack; Vertebral artery dissection; Brain tumor (n=111, 5%) |
| **AUROC** | ABCD2: 0.67 (0.62–0.71) TriAGe+: 0.80 (0.76–0.84) PCI: 0.82 (0.78–0.86) Sudbury: 0.85 (0.82–0.88) | 0.79 (0.73–0.85) | 0.82 (0.78–0.86) | 0.82 (0.77–0.87) | 0.97 (NA) |

AUROC: Area under the receiver operating characteristic curve; ED: emergency department; *PCI confirmed/denied = posterior circulation ischemia confirmed/denied by two neurologists and magnetic resonance imaging (MRI); **risk factor: age≥40y/hypertension/diabetes/coronary heart disease/ischemic stroke history/smoking; Hb: hemoglobin; Glu glucose; BP: blood pressure; SBP: systolic blood pressure; GCS: Glasgow coma scale; NA: not available.

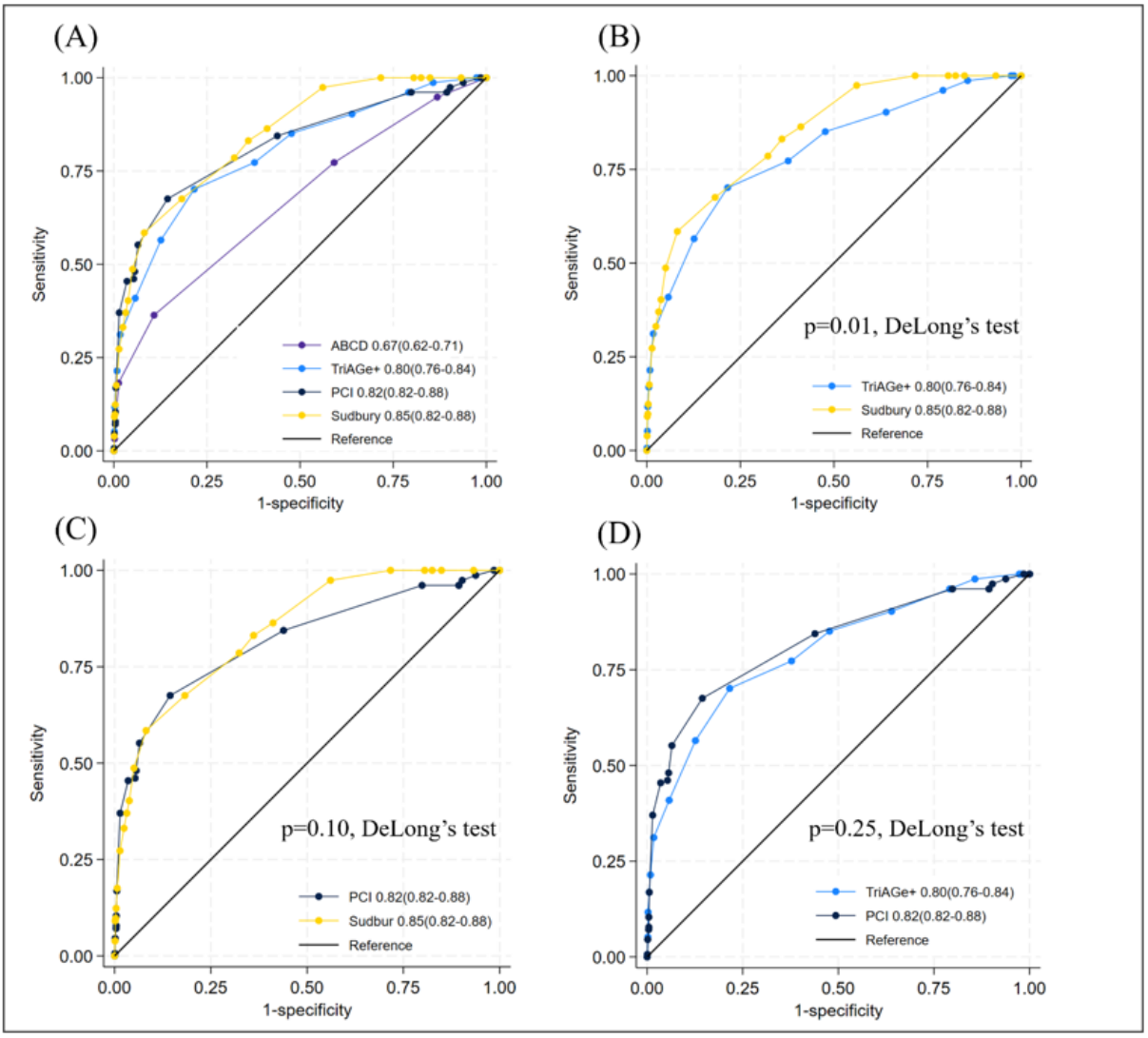


**Figure 2:** Receiver operating characteristic (ROC) curves for the detection of central lesions in patients presenting with dizziness. (A) Comparison of ABCD2, TriAGe+, PCI, and Sudbury scores; (B) Comparison of TriAGe+ and Sudbury scores; (C) Comparison of PCI and Sudbury scores; (D) Comparison of TriAGe+ and PCI scores.

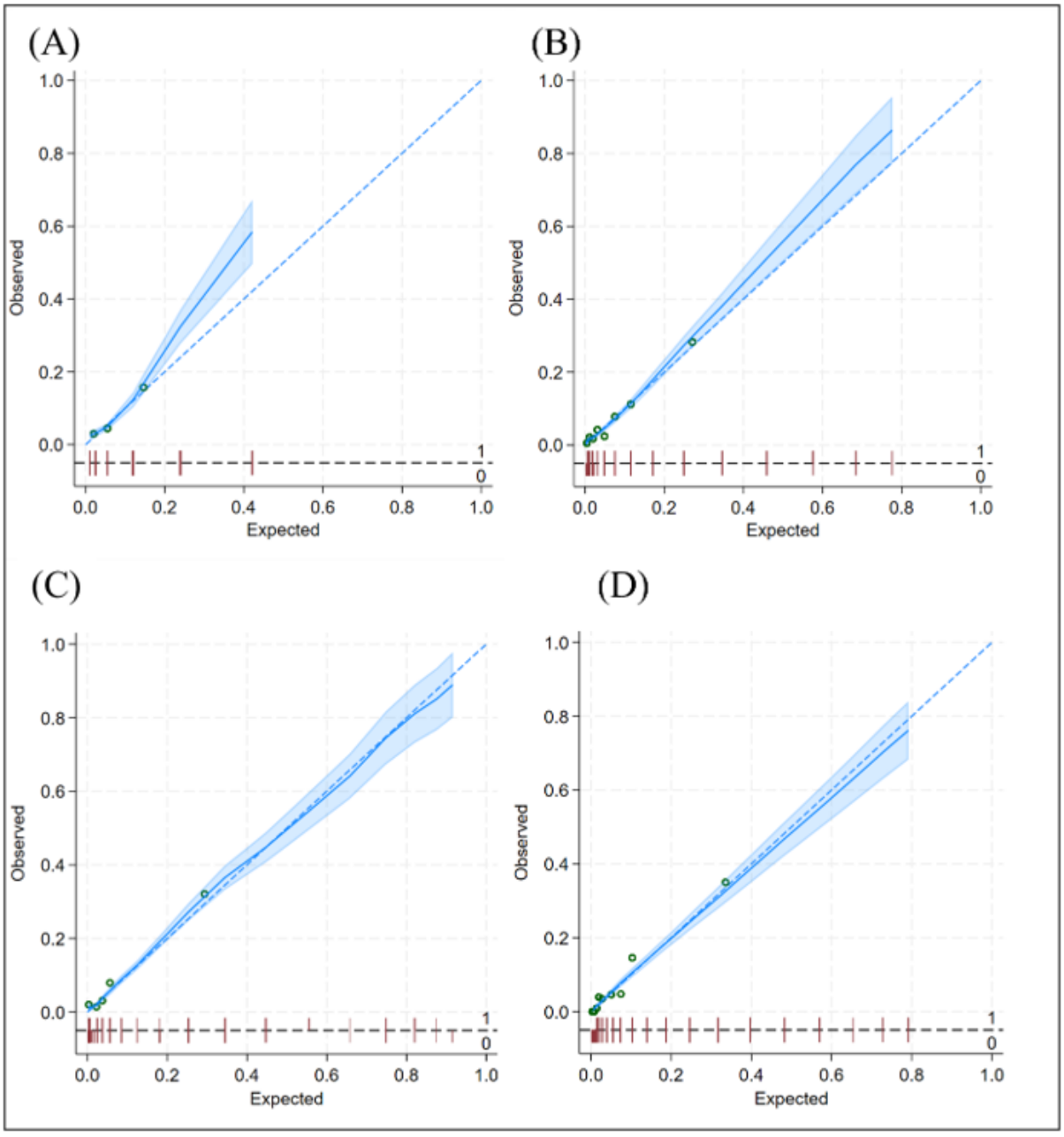


**Figure 3:** Calibration plots for the prediction of central lesions in patients presenting with dizziness. (A) ABCD2 score, (B) TriAGe+ score, (C) PCI risk score, and (D) Sudbury Vertigo Risk Score.

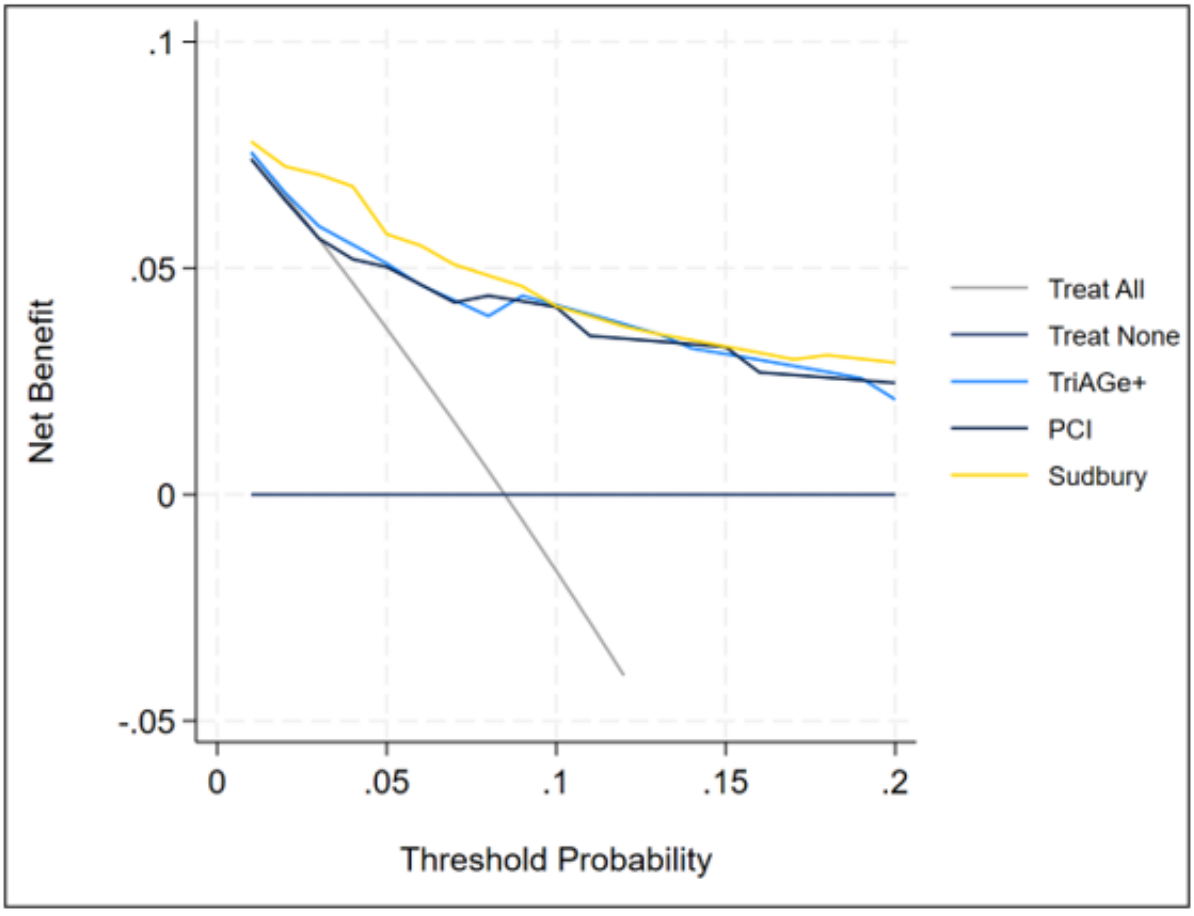


**Figure 4:** Decision curve analysis for predicting central lesions by studied risk scores in patients presenting with dizziness.