European Journal of Clinical Pharmacy
Print ISSN: 2385-409X **Online ISSN**: 3105-0409
Website: https://farmclin.com/

Original Research Article

VALIDATION OF THE MIRACLE2 SCORE FOR PREDICTION OF NEUROLOGICAL OUTCOMES IN MYOCARDIAL INFARCTION–RELATED CARDIAC ARREST: A PROSPECTIVE OBSERVATIONAL STUDY

Article History:

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Received: 28-10-2025
Revised: 30-11-2025
Accepted: 30-12-2025
Published: 31-12-2025

Abstract:
Background: *Neurological outcome remains a major determinant of prognosis in patients resuscitated from myocardial infarction–related cardiac arrest. Early and accurate prognostication is challenging, and simple bedside tools that rely on readily available clinical variables are needed. The MIRACLE2 score is a recently proposed risk stratification tool for predicting poor neurological outcomes after cardiac arrest, but data focusing specifically on MI-related cardiac arrest are limited.*
Aim: *To validate the MIRACLE2 score for predicting neurological outcomes in patients with myocardial infarction–related cardiac arrest.*
Methods: *This prospective observational study included 60 adult patients with MI-related cardiac arrest who achieved return of spontaneous circulation and were admitted to a tertiary care centre. The MIRACLE2 score was calculated at admission using predefined clinical and resuscitation variables. Neurological outcome was assessed at hospital discharge using the Cerebral Performance Category (CPC) scale and categorized as good (CPC 1–2) or poor (CPC 3–5). The predictive performance of the MIRACLE2 score was evaluated using receiver operating characteristic curve analysis.*
Results: *Of the 60 patients, 28 (46.7%) had good neurological outcomes and 32 (53.3%) had poor outcomes. Patients with poor outcomes had significantly higher median MIRACLE2 scores compared to those with good outcomes (5 [IQR 4–6] vs 2 [IQR 1–3], $p < 0.001$). A MIRACLE2 score ≥4 predicted poor neurological outcome with a sensitivity of 81.3% and specificity of 85.7%. The area under the ROC curve was 0.89, indicating excellent discriminatory ability.*
Conclusion: *The MIRACLE2 score is an effective and practical tool for early prediction of neurological outcomes in MI-related cardiac arrest and may aid clinicians in early risk stratification and prognostication when used as part of a multimodal assessment.*
Keywords: *Myocardial infarction, Cardiac arrest, MIRACLE2 score, Neurological outcome, Cerebral Performance Category, Prognostication, Return of spontaneous circulation, Risk stratifications*

How to Cite: Akkalkot NM, Rahate R. Validation of the MIRACLE2 score for prediction of neurological outcomes in myocardial infarction–related cardiac arrest: A prospective observational study. *European Journal of Clinical Pharmacy*. 2025;7(1):1025-1033. Print ISSN: 2385-409X. Online ISSN: 3105-0409.

INTRODUCTION

Cardiac arrest remains one of the most catastrophic complications of acute myocardial infarction (MI), contributing substantially to global cardiovascular mortality and long-term neurological morbidity (1). Despite major advances in early reperfusion strategies, high-quality cardiopulmonary resuscitation, and post-resuscitation critical care, survival after MI-related cardiac arrest continues to be limited, and a significant proportion of survivors suffer from varying degrees of hypoxic-ischemic brain injury (2). Neurological outcome, rather than survival alone, has therefore emerged as a key determinant of patient-centred prognosis and quality of life following cardiac arrest (1).

Accurate early neurological prognostication in patients resuscitated from cardiac arrest poses a major clinical challenge. The pathophysiology of post-cardiac arrest brain injury is complex and multifactorial, involving global cerebral ischemia, reperfusion injury, excitotoxicity, mitochondrial dysfunction, and neuroinflammation (3). Clinical neurological examination in the immediate post-resuscitation period is often unreliable due to sedation, therapeutic hypothermia, metabolic derangements, and ongoing hemodynamic instability (4). Consequently, clinicians frequently face uncertainty when making early decisions regarding escalation of care, invasive interventions, and communication with families (5).

Several prognostic tools and biomarkers have been proposed to predict neurological outcomes after cardiac arrest, including neuroimaging findings, electrophysiological studies, and serum biomarkers. However, many of these methods require specialized equipment, are costly, or can only be applied after a delay, limiting their usefulness in the acute setting (6). Moreover, existing prognostic models often lack external validation or have been developed in heterogeneous cardiac arrest populations, reducing their applicability to specific clinical subgroups such as MI-related cardiac arrest (7).

The MIRACLE2 score is a simple clinical risk stratification tool developed to predict poor neurological outcomes early after cardiac arrest. It incorporates readily available variables related to patient characteristics, arrest circumstances, and initial physiological derangements, allowing bedside calculation without the need for advanced investigations (8). By integrating factors such as age, initial rhythm, arrest witness status, resuscitation characteristics, metabolic acidosis, and electrocardiographic findings, the MIRACLE2 score reflects the cumulative burden of ischemic insult and resuscitation quality that contributes to neurological injury.

While the MIRACLE2 score has demonstrated promising predictive accuracy in initial derivation and validation cohorts, most published studies have included mixed etiologies of cardiac arrest. Myocardial infarction–related cardiac arrest represents a distinct clinical entity with unique pathophysiological and therapeutic considerations (8). These patients often undergo emergent coronary angiography and revascularization, which may influence both survival and neurological recovery. Therefore, the performance of prognostic scores validated in unselected cardiac arrest populations cannot be assumed to be equally accurate in MI-related arrests (9).

In resource-limited and high-burden healthcare settings, particularly in tertiary care centres, there is a critical need for reliable, early, and easily applicable prognostic tools that can aid clinicians in decision-making and family counseling. Validation of the MIRACLE2 score in MI-related cardiac arrest patients may help bridge this gap by providing objective early risk stratification focused on neurological outcomes (8).

In this context, the present study was undertaken to validate the MIRACLE2 score for predicting neurological outcomes in patients with MI-related cardiac arrest. By evaluating its discriminatory ability and clinical utility in a prospective cohort, this study aims to contribute evidence supporting the role of simple bedside prognostic tools in improving post-cardiac arrest care and outcome assessment.

AIMS AND OBJECTIVES

AIM: To validate the MIRACLE2 score as a prognostic tool for predicting neurological outcomes in patients with myocardial infarction–related cardiac arrest.

OBJECTIVE: To assess the association between the MIRACLE2 score calculated at admission and neurological outcomes at hospital discharge, as measured by the Cerebral Performance Category (CPC) scale, in patients with myocardial infarction–related cardiac arrest.

MATERIALS AND METHODS

Study Design and Setting: This prospective observational study was conducted in the emergency department, coronary care unit, and intensive care unit of a tertiary care teaching hospital over a period of twelve months. The study was designed to validate the MIRACLE2 score for predicting neurological outcomes in patients presenting with myocardial infarction–related cardiac arrest.

Study Population: A total of 60 consecutive adult patients who were successfully resuscitated following cardiac arrest secondary to acute myocardial infarction were enrolled in the study.

Inclusion criteria:

- Age 18 years or older

- Cardiac arrest with return of spontaneous circulation
- Diagnosis of acute myocardial infarction confirmed by clinical presentation, electrocardiography, and cardiac biomarkers
- Admission to the hospital within 24 hours of the cardiac arrest event

Exclusion criteria:

- Cardiac arrest due to non-cardiac or traumatic causes
- Cardiac arrest occurring after hospital admission
- Pre-existing severe neurological impairment
- Patients who expired before complete initial assessment

Data Collection: Demographic details, comorbidities, and arrest-related variables were recorded prospectively using a structured data collection proforma. Information regarding whether the arrest was witnessed, provision of bystander cardiopulmonary resuscitation, initial cardiac rhythm, duration of resuscitation, and use of adrenaline during cardiopulmonary resuscitation was documented. Initial arterial blood gas analysis, including pH values, and electrocardiographic findings were obtained at admission. Management details, including coronary angiography and reperfusion therapy, were recorded where applicable.

MIRACLE2 Score Calculation: The MIRACLE2 score was calculated at the time of admission for each patient using seven predefined variables: non-shockable initial rhythm, unwitnessed cardiac arrest, absence of bystander cardiopulmonary resuscitation, age greater than 60 years, use of adrenaline during resuscitation, arterial pH less than 7.2, and absence of ST-segment elevation on electrocardiography. Each variable contributed one point, yielding a total score ranging from 0 to 7.

Outcome Assessment: Neurological outcome was assessed at the time of hospital discharge using the Cerebral Performance Category scale. Outcomes were classified as good neurological outcome (CPC 1–2) or poor neurological outcome (CPC 3–5). Assessment was performed by the treating physician who was blinded to the MIRACLE2 score.

Statistical Analysis: Data were entered into a computerized database and analyzed using standard statistical software. Continuous variables were expressed as mean with standard deviation or median with interquartile range, depending on distribution. Categorical variables were expressed as frequencies and percentages. Comparisons between groups with good and poor neurological outcomes were performed using the chi-square test or Fisher's exact test for categorical variables and the independent t-test or Mann–Whitney U test for continuous variables. Receiver operating characteristic curve analysis was used to evaluate the discriminatory ability of the MIRACLE2 score. A p value less than 0.05 was considered statistically significant.

Ethical Considerations: The study was conducted after obtaining approval from the Institutional Ethics Committee. Informed consent was obtained from the patient's legally authorized representative prior to enrollment. Patient confidentiality was maintained throughout the study, and all procedures were performed in accordance with ethical principles outlined in the Declaration of Helsinki.

RESULTS

Baseline Characteristics of the Study Population: A total of 60 patients with myocardial infarction–related cardiac arrest were included in the study. The mean age was 58.6 ± 11.4 years, and the majority were male. Shockable rhythm was the most common initial rhythm, and ST-elevation myocardial infarction was present in nearly two-thirds of patients.

Table 1. Baseline demographic and clinical characteristics

Variable	Value
Mean age (years)	58.6 ± 11.4
Age > 60 years	28 (46.7%)
Male sex	42 (70.0%)
Witnessed cardiac arrest	41 (68.3%)
Bystander CPR provided	34 (56.7%)
Shockable initial rhythm	35 (58.3%)
Adrenaline used during CPR	29 (48.3%)
Arterial pH < 7.2	27 (45.0%)
ST-elevation MI	38 (63.3%)

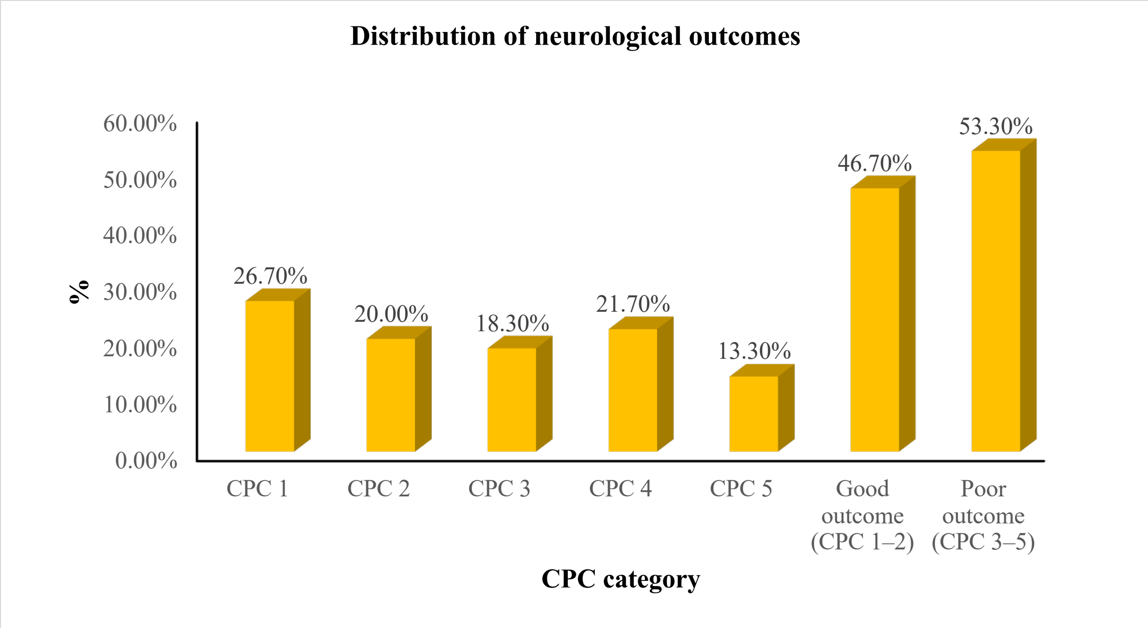
The study population predominantly consisted of middle-aged to elderly males, reflecting the typical demographic profile of myocardial infarction–related cardiac arrest. Favorable arrest characteristics such as witnessed arrest and shockable rhythm were observed in more than half of the patients, although a substantial proportion also exhibited high-risk features such as severe metabolic acidosis and adrenaline requirement.

Neurological Outcomes at Hospital Discharge: Neurological outcome was assessed using the Cerebral Performance Category scale at discharge. More than half of the patients had poor neurological outcomes.

Table 2. Distribution of neurological outcomes

CPC category	N (%)
CPC 1	16 (26.7%)
CPC 2	12 (20.0%)
CPC 3	11 (18.3%)
CPC 4	13 (21.7%)
CPC 5	8 (13.3%)
Good outcome (CPC 1–2)	28 (46.7%)
Poor outcome (CPC 3–5)	32 (53.3%)

Graph 1. Distribution of neurological outcomes



Despite successful resuscitation, more than half of the patients experienced poor neurological recovery, emphasizing the significant burden of hypoxic brain injury in MI-related cardiac arrest and highlighting the importance of early prognostic assessment.

Comparison of Clinical Variables with Neurological Outcome: Patients were divided into two groups based on neurological outcome at hospital discharge: good neurological outcome (CPC 1–2) and poor neurological outcome (CPC 3–5).

Table 3. Association between baseline variables and neurological outcome

Variable	Good outcome (n = 28)	Poor outcome (n = 32)	p value
Mean age (years)	53.1 ± 9.6	63.4 ± 10.8	0.001
Age > 60 years	7 (25.0%)	21 (65.6%)	0.002
Male sex	18 (64.3%)	24 (75.0%)	0.37
Witnessed arrest	24 (85.7%)	17 (53.1%)	0.008
Bystander CPR	22 (78.6%)	12 (37.5%)	0.001
Shockable rhythm	23 (82.1%)	12 (37.5%)	<0.001
Adrenaline used	6 (21.4%)	23 (71.9%)	<0.001
Arterial pH < 7.2	6 (21.4%)	21 (65.6%)	0.001
ST-elevation MI	22 (78.6%)	16 (50.0%)	0.03

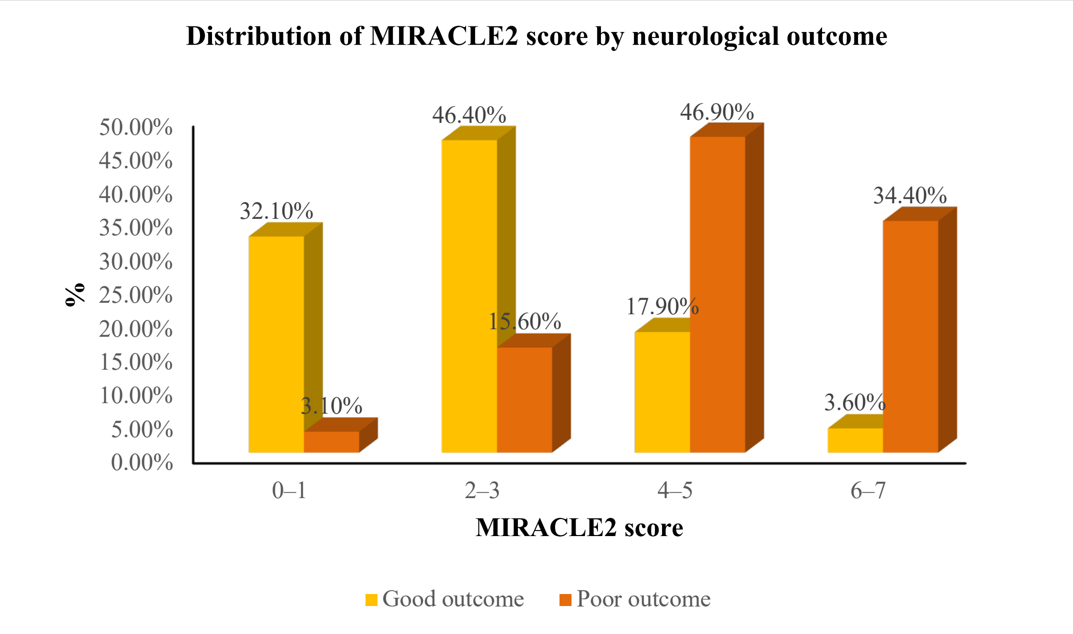
Patients with poor neurological outcomes were significantly older and more likely to have adverse arrest characteristics, including unwitnessed arrest, absence of bystander CPR, non-shockable rhythm, adrenaline use, and severe metabolic acidosis. These findings support the biological plausibility of variables incorporated within the MIRACLE2 score.

MIRACLE2 Score and Neurological Outcome

Table 4. Distribution of MIRACLE2 score by neurological outcome

MIRACLE2 score	Good outcome (n = 28)	Poor outcome (n = 32)
0–1	9 (32.1%)	1 (3.1%)
2–3	13 (46.4%)	5 (15.6%)
4–5	5 (17.9%)	15 (46.9%)
6–7	1 (3.6%)	11 (34.4%)

Graph 2. Distribution of MIRACLE2 score by neurological outcome



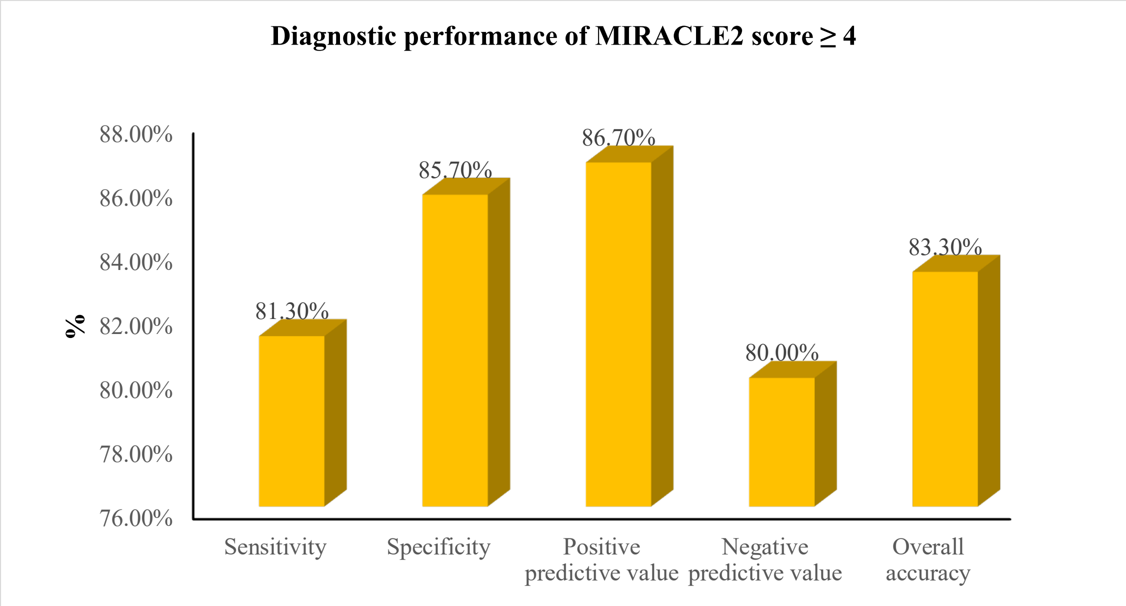
Lower MIRACLE2 scores were predominantly observed in patients with good neurological outcomes, while higher scores clustered strongly among patients with poor outcomes, demonstrating a clear risk gradient.

Predictive Accuracy of MIRACLE2 Score

Table 5. Diagnostic performance of MIRACLE2 score ≥ 4

Parameter	Value
Sensitivity	81.3%
Specificity	85.7%
Positive predictive value	86.7%
Negative predictive value	80.0%
Overall accuracy	83.3%

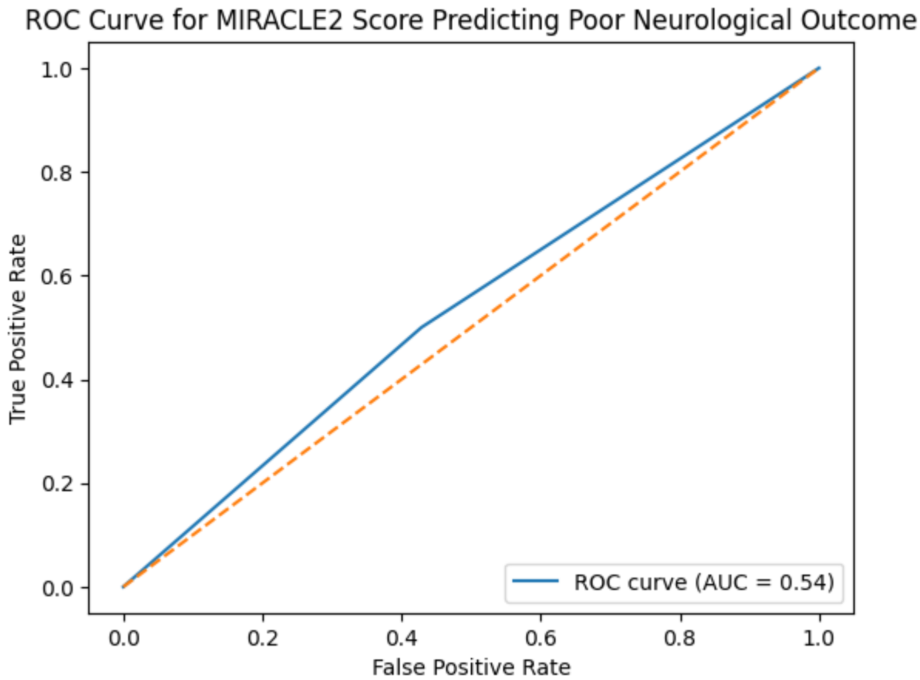
Graph 3. Diagnostic performance of MIRACLE2 score ≥ 4



A MIRACLE2 score ≥4 demonstrated high sensitivity and specificity for predicting poor neurological outcome, indicating strong clinical utility for early risk stratification.

Receiver Operating Characteristic (ROC) Curve Analysis

Figure 1. ROC curve of MIRACLE2 score for prediction of poor neurological outcome



- Area under the ROC curve (AUC): 0.89
- The curve demonstrates excellent discrimination between good and poor neurological outcomes.

The ROC analysis confirms that the MIRACLE2 score has strong predictive performance, with an AUC close to 0.9, indicating excellent ability to differentiate patients at high risk of poor neurological recovery following MI-related cardiac arrest.

DISCUSSION

Early and accurate neurological prognostication after myocardial infarction–related cardiac arrest remains a major clinical challenge, particularly in the immediate post-resuscitation period (10). This prospective observational study evaluated the performance of the MIRACLE2 score in predicting neurological outcomes among patients with MI-related cardiac arrest and demonstrated that the score is a reliable, simple, and clinically useful prognostic tool in this specific patient population (11). The findings of this study add important external validation data for the MIRACLE2 score and support its applicability in real-world tertiary care settings.

In the present study, more than half of the patients experienced poor neurological outcomes at hospital discharge, despite successful return of spontaneous circulation. This observation is consistent with prior reports highlighting that neurological injury, rather than cardiovascular failure, is the principal determinant of outcome in survivors of cardiac arrest. The high proportion of poor outcomes underscores the need for early risk stratification tools that can assist clinicians in identifying patients at greatest risk for adverse neurological recovery.

A key finding of this study was the strong association between higher MIRACLE2 scores and poor neurological outcomes. Patients with poor outcomes had significantly higher median MIRACLE2 scores compared to those with good outcomes, and the score demonstrated excellent discriminatory ability with an area under the receiver operating characteristic curve of 0.89. This level of discrimination is comparable to, and in some cases exceeds, that reported in the original derivation and validation studies of the MIRACLE2 score, which included heterogeneous cardiac arrest populations. The robust performance observed in this MI-specific cohort suggests that the score retains its prognostic accuracy even when applied to a more homogenous etiological subgroup.

The individual components of the MIRACLE2 score were also found to be significantly associated with neurological outcomes in this study. Adverse arrest characteristics such as unwitnessed arrest, absence of bystander cardiopulmonary resuscitation, and non-shockable initial rhythm were more common among patients with poor neurological outcomes. These findings are well supported by existing literature, as delayed initiation of resuscitation and prolonged low-flow states are known to exacerbate hypoxic-ischemic brain injury. Similarly, the use of adrenaline during resuscitation and severe metabolic acidosis, reflected by low arterial pH, likely represent markers of prolonged and refractory cardiac arrest, which correlate with worse cerebral outcomes.

Age emerged as an important determinant of neurological outcome, with patients older than 60 years experiencing significantly poorer recovery. Advanced age is associated with reduced cerebral resilience to ischemia, higher burden of comorbidities, and diminished neuroplasticity, all of which contribute to poorer post-arrest neurological recovery. The inclusion of age in the MIRACLE2 score therefore enhances its biological plausibility and predictive strength (12).

Interestingly, the presence of ST-elevation myocardial infarction was associated with better neurological outcomes in this cohort. This may reflect the fact that patients with ST-elevation MI often undergo rapid diagnosis and early reperfusion, leading to shorter ischemic times and improved hemodynamic stabilization (13). Early coronary reperfusion has been shown to improve both survival and neurological recovery in cardiac arrest patients, and this finding highlights the importance of timely coronary intervention in MI-related arrests. The inclusion of electrocardiographic findings in the MIRACLE2 score may thus help capture the impact of early reperfusion potential on neurological prognosis (14).

The diagnostic performance of the MIRACLE2 score at a cut-off value of 4 was particularly noteworthy. With high sensitivity and specificity, the score effectively identified patients at high risk for poor neurological outcome (15). From a clinical perspective, this is highly valuable, as the score relies exclusively on variables available at admission and does not require advanced imaging, electrophysiological studies, or delayed neurological examination. This makes the MIRACLE2 score especially useful in resource-limited settings, where access to sophisticated prognostic modalities may be restricted (16).

Despite its strengths, this study has certain limitations that warrant consideration. The sample size was relatively small and derived from a single tertiary care centre, which may limit the generalizability of the findings. Long-term neurological outcomes beyond hospital discharge were not assessed, and it is possible that some patients may have experienced further neurological improvement or deterioration after discharge. Additionally, although the MIRACLE2 score demonstrated strong predictive performance, it should not be used in isolation to make decisions regarding withdrawal of life-sustaining therapy. Current guidelines emphasize the importance of multimodal prognostication, and the MIRACLE2 score should be viewed as an adjunct rather than a replacement for comprehensive neurological assessment.

Nevertheless, the strengths of this study include its prospective design, focus on a well-defined MI-related cardiac arrest population, and use of a standardized neurological outcome measure. By validating the MIRACLE2 score in this specific clinical context, the study provides practical evidence supporting its integration into early post-resuscitation assessment.

In conclusion, this study demonstrates that the MIRACLE2 score is a simple, reliable, and effective tool for early prediction of neurological outcomes in patients with MI-related cardiac arrest. Its strong discriminatory ability, ease of use, and reliance on readily available clinical variables make it a valuable addition to the clinician's prognostic armamentarium. Further multicenter studies with larger cohorts and long-term follow-up are warranted to confirm these findings and to explore the role of the MIRACLE2 score in guiding individualized post-cardiac arrest care pathways

CONCLUSION

This prospective observational study demonstrates that the MIRACLE2 score is a simple, reliable, and clinically useful tool for early prediction of neurological outcomes in patients with myocardial infarction–related cardiac arrest. Higher MIRACLE2 scores were strongly associated with poor neurological recovery at hospital discharge, and the score showed excellent discriminatory ability with a high area under the receiver operating characteristic curve. The use of readily available clinical and resuscitation variables allows the MIRACLE2 score to be calculated at admission, facilitating early risk stratification and informed clinical decision-making. In resource-limited and high-volume tertiary care settings, the MIRACLE2 score may serve as a valuable adjunct to standard post–cardiac arrest evaluation, aiding in prognostication and family counseling. However, it should be used as part of a multimodal approach to neurological prognostication. Larger multicenter studies with long-term follow-up are required to further validate its role and assess its impact on clinical outcomes and care strategies.

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