Performance of ICU Mortality Prediction Models and Determinants of Outcomes at Moi Teaching and Referral Hospital, Kenya: Comparative Analysis of APACHE II, MPM_0 III, and R-MPM

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Abstract

Background

Intensive care unit (ICU) mortality remains a major challenge in low- and middle-income countries. Limited financial, human and infrastructural resources further constrain critical care delivery. Severity scoring and prognostic models such as the Acute Physiology and Chronic Health Evaluation II (APACHE II), Mortality Probability Model III at admission (MPM_0 III), and Rwanda Mortality Prediction Model (R-MPM) can used to estimate ICU mortality. However, their uptake and utilization in African settings remains low.

Methods

We conducted a cross-sectional study among 416 adult patients admitted to the ICU at Moi Teaching and Referral Hospital (MTRH), Kenya, between October 2022 and July 2023. Data on demographic, clinical, physiological, and laboratory characteristics were collected within 24 hours of ICU admission. ICU mortality was the primary outcome. Model performance was assessed using discrimination by area under the receiver operating characteristic curve (AUROC) and calibration using the Hosmer–Lemeshow goodness-of-fit test.

Findings

The mean age of the study participants was 42 years (SD 20), and 57% of patients were male The ICU mortality rate was 29% (120/416). APACHE II demonstrated the best discrimination for ICU mortality (AUROC 0·77, 95% CI 0·72–0·82), followed by MPM_0 III (0·72, 0·67–0·78), while R-MPM had moderate discrimination (0·62, 0·56–0·68). All three models demonstrated poor calibration (Hosmer–Lemeshow $p<0·05$). Higher mortality was associated with admission from medical wards, hypotension, hypoxaemia, metabolic acidosis, acute kidney injury, and need for mechanical ventilation.

Conclusion

APACHE II and MPM_0 III showed acceptable performance in predicting ICU mortality in this Kenyan ICU as compared to R-MPM. However, all models require additional local calibration to improve their utility in triage and patient care.

Research in Context

Evidence before this study

We searched PubMed, African Journals Online, and Google Scholar for studies published between Jan 1, 2014, and Dec 31, 2021, using the terms "ICU mortality", "APACHE II", "MPM_0 III", "R-MPM", "Kenya", and "sub-Saharan Africa". Previous studies from sub-Saharan Africa reported ICU mortality rates ranging from 27% to 64%, with variable performance of mortality prediction models. APACHE II, R-MPM and MPM_0 III generally demonstrated good discrimination.

Added value of this study

This study provides one of the first direct comparisons of APACHE II, MPM_0 III, and R-MPM in a Kenyan tertiary referral hospital ICU. We found that APACHE II had the best predictive performance, while R-MPM performed less well than expected despite being designed and validated for use in resource-limited settings.

Implications of all the available evidence

Existing ICU prognostic models may support triage in African ICUs but would benefit from local calibration. Development of simplified models based on locally relevant variables could improve prediction, accuracy and proper resource allocation and utilization.

Introduction

Critical illness contributes substantially to mortality worldwide, particularly in low- and middle-income countries where access to intensive care is limited [12]. Intensive care units are designed to provide specialized support for critically ill patients; however, provision of ICU services in resource-constrained settings is hindered by shortages of equipment, limited numbers of trained personnel, and inadequate bed capacity [1,7]. Kenya has approximately 537 ICU and high dependency unit beds for a population of nearly 47 million, representing less than 1% of total hospital bed capacity.

Scarcity of ICU beds creates difficult triage decisions. Clinicians are frequently required to choose between several critically ill patients who meet ICU admission criteria. These decisions are often based on subjective judgement and experience. Mortality prediction models offer an objective method to support decision making by estimating the likelihood of benefit from ICU care based on physiological and clinical variables.

The APACHE II and MPM_0 III scores are among the most widely used ICU prognostic tools globally [8,16,18]. APACHE II incorporates acute physiological measurements, age, and chronic illness, while MPM_0 III uses clinical and physiological variables available at admission. Both models have shown good performance in high-income settings but may be less applicable in low-resource environments because they depend on laboratory tests or variables that are not consistently available.

The Rwanda Mortality Prediction Model was developed specifically for low-resource settings using fewer, readily available variables [9]. Although it has been validated in Rwanda and other settings, evidence of its performance in Kenya is limited [11].

This study aimed to estimate ICU mortality at Moi Teaching and Referral Hospital and compare the performance of APACHE II, MPM_0 III, and R-MPM in predicting mortality among critically ill adults.

Methods

Study design and setting

This cross-sectional study was conducted in the 20-bed mixed medical-surgical ICU at Moi Teaching and Referral Hospital, a tertiary referral hospital in western Kenya.

Sample size calculation and participant selection criteria

Studies carried out in Africa and other lower middle-income countries, the sensitivity of the APACHE II model was 88% whereas those of MPM_0 III and Rwanda MPM are 72% and 81% respectively. Based on this information, we used the formula for detecting significant difference between two populations and compared each of the three models against each other. The pair that yielded the highest sample size of 416 participants was used for this study.

Adult patients aged 18 years and older admitted to the ICU between Oct 1, 2022, and July 31, 2023, were eligible. Patients younger than 18 years were excluded from the study since it's use is not validated for persons below this age. Also, those without consent, and those with missing variables required for model calculation were excluded.

Procedures, data collection

Data was collected within 24 hours of ICU admission using a structured case report form. Variables included age, sex, ward of origin prior to ICU admission, comorbidities, physiological parameters, laboratory findings, and requirement for organ support.

Outcomes

The primary outcome was ICU mortality. Secondary outcomes included length of ICU stay and comparative performance of the three mortality prediction models.

Statistical analysis

Continuous variables were summarised using means and standard deviations or medians and interquartile ranges, as appropriate. Categorical variables were presented as frequencies and percentages. Measures of association, bivariate and multivariate analysis were carried out on the categorical variables. P values <0.05 were considered to be statistically significant.

For APACHE II, disease severity score and the respective mortality probability score was generated using a web-based software (MDCalc®). For MPM_0 III scores were calculated using web-based software (UpToDate®). R-MPM beta coefficients were generating using odds ratios from the originating study.

The discriminative ability of each model was assessed using AUROC. Values between 0·70 and 0·79 were considered good, and values of 0·80 or greater were considered very good. Calibration was assessed using the Hosmer–Lemeshow goodness-of-fit test. Correlation between models was assessed using Pearson correlation coefficients.

Ethics

The study was approved by the Moi University/MTRH Institutional Research and Ethics Committee (FAN 0004097) and the National Commission for Science, Technology and Innovation (Research license number 608027). Written informed consent was obtained from patients or their next of kin prior to enrollment in the study. Utmost confidentiality was ensured throughout the study.

Results

A total of 416 patients were included in the analysis. The mean age was 42 years (SD 20; range 18–95 years), and 237 (57%) were male. Most admissions originated from the operating theatre (266 [64%]), followed by the emergency department and medical wards.

The median length of ICU stay was 3 days (IQR 2–6). Most patients required mechanical ventilation (246 [59%]), while 91 (22%) required both ventilatory and inotropic support.

Overall ICU mortality was 29% (120/416). Mortality was highest among patients admitted from medical wards (49%) and lowest among post-operative patients.

Physiological abnormalities associated with mortality included hypotension, tachycardia, hypoxaemia, metabolic acidosis, elevated serum creatinine, and low Glasgow Coma Scale score. Patients requiring mechanical ventilation or vasopressor support had significantly higher mortality than those who did not.

APACHE II scores were significantly higher among non-survivors than survivors. APACHE II showed the best discrimination for ICU mortality (AUROC 0·77, 95% CI 0·72–0·82). MPM_0 III had slightly lower but acceptable discrimination (0·72, 0·67–0·78), whereas R-MPM had moderate discrimination (0·62, 0·56–0·68). The APACHE II model demonstrated a sensitivity of 58% and a specificity of 84%. As such, this model was effective in identifying survivors than detecting non-survivors.

The MPM_0 III model showed a higher sensitivity of 68% but a lower specificity of 72%, suggesting a better ability to detect patients at risk of mortality as compared to APACHE II. In contrast, the R-MPM model had a sensitivity of 64% and the lowest specificity at 55%,

indicating relatively lower accuracy in both detecting mortality and correctly identifying survivors.

All models demonstrated poor calibration, with Hosmer–Lemeshow (H-L) p values below 0·05. For the APACHE II model, the H–L statistic was 13.6 with a p-value of 0.03. This shows that there is a statistically significant difference between observed and expected outcomes. This means that this model may be less accurate in estimating the actual probability of death across the entire range of predicted mortalities. Similarly, both the MPM_0 III and R-MPM models showed poor calibration, with H–L statistics of 54.518 ($p < 0.001$) and 172.8 ($p < 0.001$), respectively. The highly significant p-values indicate substantial discrepancies between predicted and observed mortality across the risk groups, with the R-MPM model demonstrating the worst calibration among the three.

Correlation between APACHE II and MPM_0 III was moderate (r = 0.56, 95% CI: 0.49–0.62), while correlation between APACHE II and R-MPM (r = 0.46, 95% CI: 0.39–0.54) and between MPM_0 III and R-MPM (r = 0.44, 95% CI: 0.36–0.51) was weaker. The moderate positive correlation between APACHE II and MPM_0 III, indicate that as the predicted mortality risk by one model increased, there was a corresponding increase in the predicted risk by the other model. This suggests a reasonable level of agreement between the two models, with approximately 56% of the variability in one model's predictions being explained by the other. However, the correlation is not strong enough to imply interchangeable utility between the models. Similarly, moderate positive correlations were observed between APACHE II and R-MPM, and between MPM_0 III and R-MPM. These weaker correlations indicate less agreement involving the R-MPM model,

Discussion

This study found an ICU mortality rate of 29%, which is comparable to rates reported in other African ICUs [4-6,10] and lower than some previous estimates from Kenya and neighbouring countries. The relatively low mortality observed may reflect the younger age profile of patients and the predominance of post-operative surgical admissions who carry a lower mortality risk.

Age is a well-recognised determinant of ICU mortality. Older adults have lower physiological reserve and a greater burden of chronic disease, leading to poorer outcomes. In our study, the relatively young mean age of 42 years may partly explain the lower mortality rate compared with studies from high-income countries where ICU populations are older.

Patients admitted from medical wards had substantially higher mortality than surgical patients. This difference likely reflects more severe illness, delayed presentation, and greater prevalence of multi-organ dysfunction among medical admissions. Surgical patients, especially those undergoing planned procedures, often have more predictable disease trajectories and better outcomes.

Among the three prognostic models evaluated, APACHE II demonstrated the best discriminative ability [8,16,17]. This finding is consistent with previous studies from low-resource settings showing that APACHE II remains a useful tool despite its complexity. However, APACHE II requires laboratory measurements that may not always be available in African ICUs.

MPM_0 III also performed reasonably well and has practical advantages because it can be calculated using variables available at ICU admission and does not necessarily require any laboratory tests [18]. Its simpler design may make it more feasible for routine use in resource-limited settings.

The R-MPM performed less well than expected. Although it was developed for low-resource settings, its lower AUROC suggests that it may not adequately capture the spectrum of critical illness in this population [9,11]. Differences in case mix, healthcare delivery, and local epidemiology may explain this reduced performance.

All three models demonstrated poor calibration. This means that although they were able to distinguish between survivors and non-survivors, they did not accurately estimate the absolute probability of death. Local recalibration using Kenyan data is therefore necessary before these models can be implemented in routine clinical practice [3,19,20].

Strengths and Limitations

The study has several strengths. It included a large sample of ICU patients and compared three commonly used mortality prediction models in the same population. However, several

limitations should be considered. This was a single-centre study, which may limit generalisability. Also, the long-term outcomes after ICU discharge were not assessed.

Conclusion

APACHE II and MPM0 III demonstrated acceptable discrimination for ICU mortality at Moi Teaching and Referral Hospital, whereas R-MPM had limited predictive performance. Nevertheless, all three models had poor calibration and require local adaptation before use in routine clinical practice. Development of locally calibrated prognostic tools may improve ICU triage, resource allocation, and patient outcomes in African critical care settings.

Contributors

All the authors participated in the entire research process from the proposal stage all the way to the manuscript writing.

Declaration of interests

The authors declare no competing interests.

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Table 1: Summary of the clinical and demographic characteristics of patients admitted to ICU

Variable	Frequency (%)/ Mean (SD)
Age (years)	
Mean (SD)	42 (20)
Range	18 - 95
Gender	
Female	179 (43%)
Male	237 (57%)
Ward	
Accident and Emergency	49 (12%)
External ICU	20 (5%)
Medical wards	49 (12%)
Surgical wards	31 (7%)
Theatre	267 (64%)
Surgery	
Elective	131 (49%)
Emergency	136 (51%)
Cardiopulmonary resuscitation (CPR) prior to ICU admission	
No	404 (97%)
Yes	12 (3%)
Suspected or confirmed infection prior to ICU admission	
No	141 (34%)
Yes	275 (66%)

Variable	Frequency (%)/ Mean (SD)
Comorbidities or chronic illnesses	
No	79 (19%)
Yes	337 (81%)
Reason/indication for ICU admission	
Close monitoring	75 (18%)
Inotropic and Ventilatory support	91 (22%)
Inotropic support	3 (1%)
Ventilatory support	247 (59%)

Table 2: Table showing the odds of mortality based on the ward of origin prior to ICU admission

	Non-Survivor	Survivor	OR (95% CI)	p value
Theatre *(Referent group)*	60	207		
Surgical wards	9	22	**1.4** (0.6 - 3.2)	0.41
External ICU	6	14	**1.5** (0.5 - 4.0)	0.45
Accident and Emergency	21	28	**2.6** (1.4 - 4.9)	0.003
Medical wards	24	25	**3.3** (1.8 - 6.2)	<0.001
TOTAL	**120**	**296**		

Table 3: Table showing summary of the performance of the variables used in the APACHE model

Variable		Outcome		OR	95% CI	P value	X^2
	Ranges	**Non - survivor**	**Survivor**				
Temperature	36.0 - 38.4 *(Referent group)*	32	245				
	Low (<36.0)	22	47	1.2	0.7 - 2.2	0.44	
	High (>38.4)	6	4	4.0	1.1 - 44.5	0.02	5.12
Blood pressure *(Mean arterial pressure in mmHg)*	70 – 109 *(Referent group)*	80	222				
	Low (<70)	25	34	2.0	1.1 - 3.6	0.01	
	High (>109)	14	40	1.0	0.5 - 2.0	0.9	
Heart rate *(Beats per minute)*	70 - 109 *(Referent group)*	51	188				
	Low (<70)	10	31	1.2	0.5 - 2.6	0.66	
	High (>109)	59	77	2.8	1.8 - 4.5	<0.001	
Respiratory rate *(Breathes per minute)*	12 - 24 *(Referent group)*	94	243				
	Low (<12)	7	16	1.1	0.5 - 2.8	0.79	
	High (>24)	19	37	1.3	0.7 - 2.4	0.36	
Oxygenation *(Pa02 in mmHg)*	Normoxaemic (≥70)	72	220	1.9	1.2 - 3.0	0.003	
	Hypoxaemic (<70)	48	76				
Serum PH on blood gas analysis	7.33 - 7.49 *(Referent group)*	54	182				

	Low (<7.33)	57	79	2.4	1.5 - 3.8	<0.001	
	High (>7.49)	9	35	0.9	0.4 - 1.9	0.72	
Serum sodium levels *(mmol/L)*	130 - 149 *(Referent group)*	76	244				
	Low (<130)	36	40	2.9	1.7 - 4.9	<0.001	
	High (>149)	8	12	2.1	0.8 - 5.4	0.1	
Serum potassium levels *(mmol/L)*	3.5 - 5.4 *(Referent group)*	84	232				
	Low (<3.5)	19	45	1.2	0.6 - 2.1	0.61	
	High (>5.4)	17	19	2.5	1.2 - 5.0	0.009	
Serum creatinine levels *(micromol/L)*	53 - 124 *(Referrent group)*	60	202				
	Low (<53)	19	58	1.1	0.6 - 2.0	0.75	
	High (>124)	41	36	3.8	2.3 - 6.5	<0.001	
White Blood Cell Count (counts per microlitre)	3,000 - 14,900 *(Referrent group)*	75	223				
	Low (<3,000)	4	0			<0.001	11.4
	High (>14,900)	41	73	1.7	1.1 - 2.7	0.03	

Table 4: Table showing the performance of the variables used in the MPM_0 III model

Variable / Outcome		Outcome		Odds Ratio	95% CI	p value	X^2
		Non-Survivor	Survivor				
Medical case or Emergency surgery	**Yes**	76	108	3.0	1.9 - 4.7	<0.001	
	No	44	188				
Cardiopulmonary resuscitation prior to ICU admission	**Yes**	5	7	1.8	0.6 - 5.8	0.32	
	No	115	289				
Coma or stupor (GCS of 3 or 4)	**Yes**	47	96	1.3	0.9 - 2.1	0.19	
	No	73	200				
Heart rate ≥ 150 beats per minute	**Yes**	8	5	4.2	1.3 - 13.0	0.008	
	No	112	291				
Systolic blood pressure ≤ 90mmHg	**Yes**	24	14	5.0	2.5 - 10.1	<0.001	
	No	96	282				
Mechanical ventilation within the 1st hour of admission	**Yes**	114	213	7.4	3.1 - 17.5	<0.001	
	No	6	83				
Acute Kidney Injury (AKI)	**Yes**	51	58	3.0	1.9 - 4.8	<0.001	
	No	69	238				
Cardiac arrythmias	**Yes**	5	14	0.9	0.3 - 2.5	0.8	

	No	115	282				
Cerebrovascular accidents	**Yes**	31	50	1.7	1.0 - 2.9	0.04	
	No	89	246				
Intracranial mass effect	**Yes**	42	88	1.3	0.8 - 2.0	0.29	
	No	78	208				
Chronic Kidney disease	**Yes**	6	7	2.2	0.7 - 6.6	0.16	
	No	114	289				
Cancer with distant metastasis	**Yes**	1	3	0.8	0.1 - 8.0	0.86	0.03
	No	119	293				
Liver cirrhosis	**Yes**	3	1	7.6	0.8 - 73.5	0.04	4.16
	No	117	295				

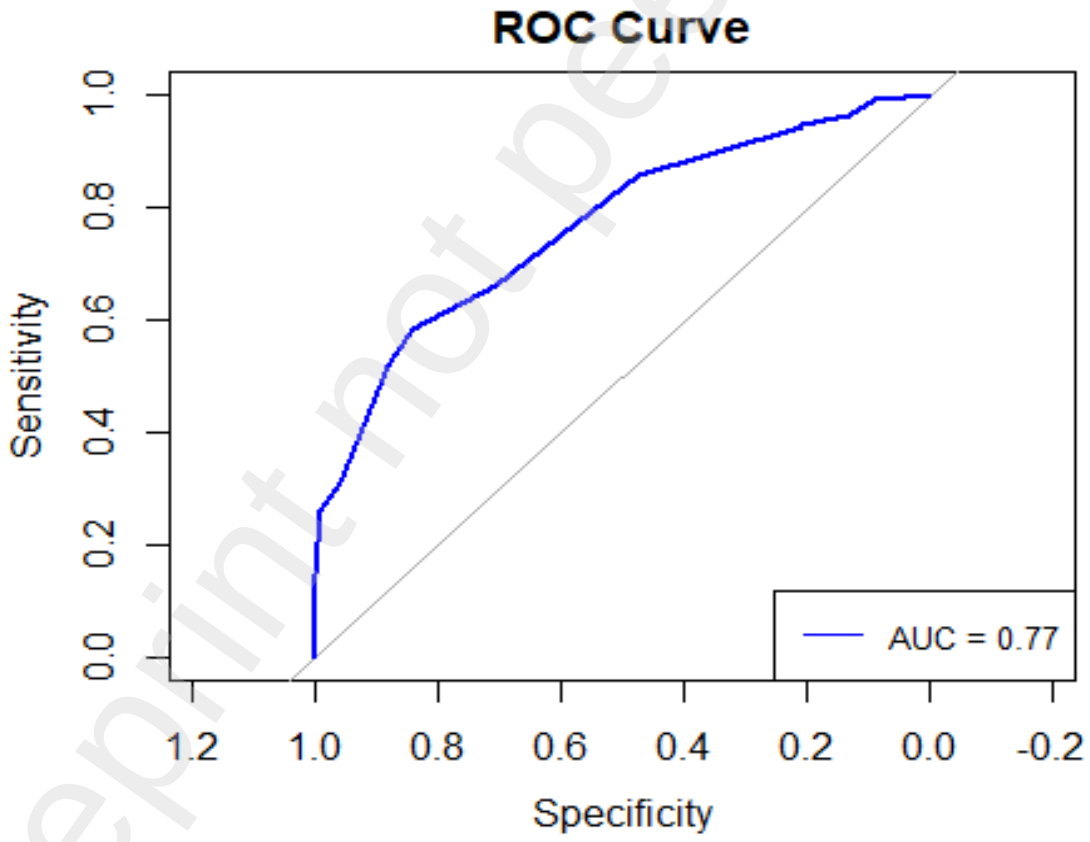

Figure 1: : Area under receiver operating characteristics curve for the APACHE II Model

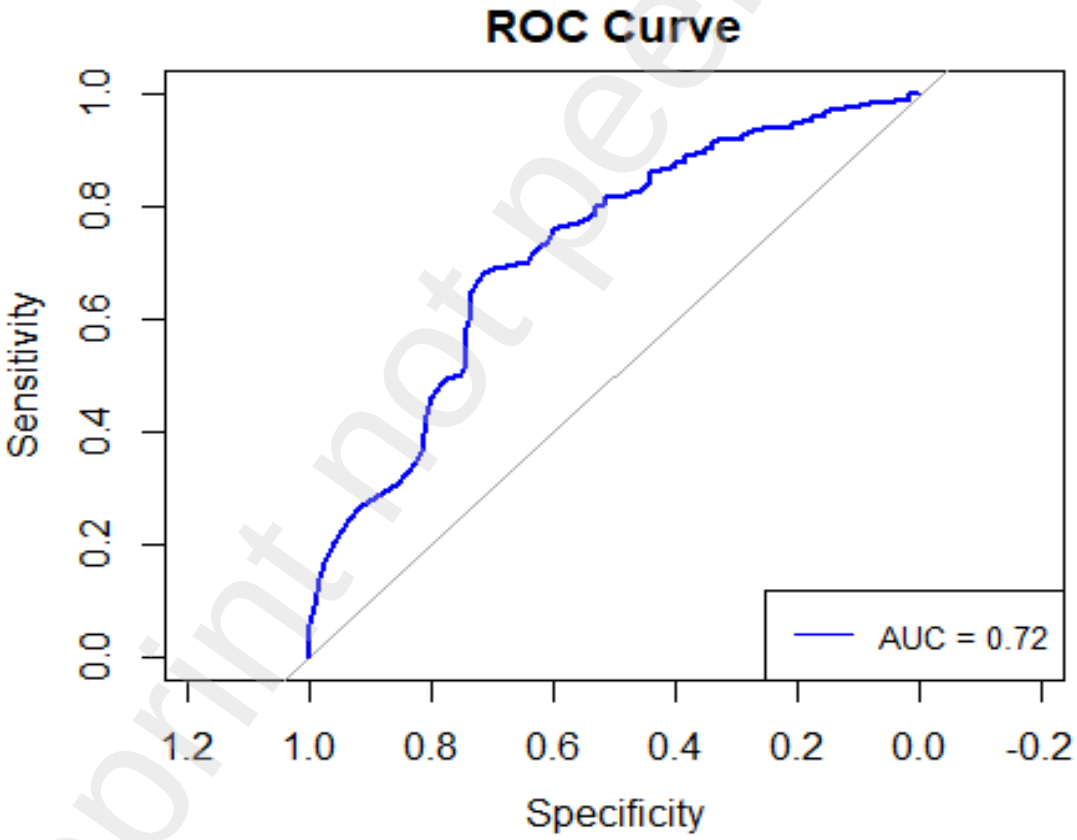

Figure 2: Area under receiver operating characteristics curve for the MPM_0 III model

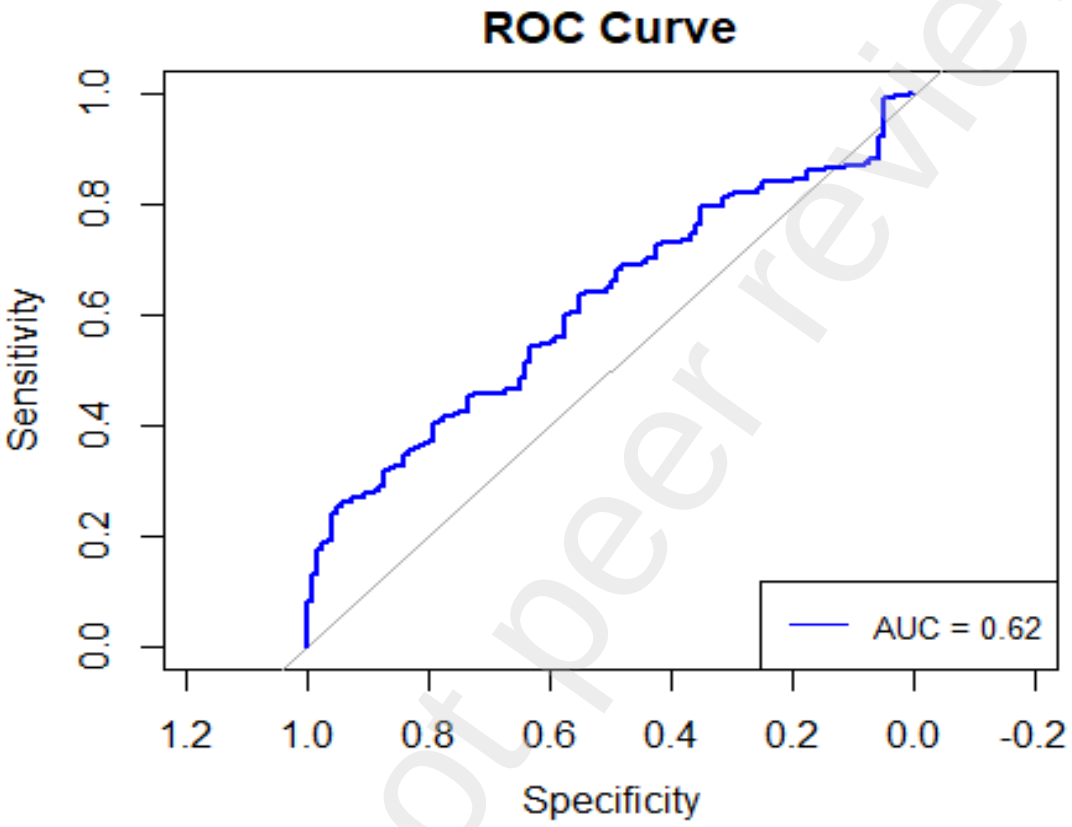

Figure 3: Area under receiver operating characteristic curve for the R-MPM model