Al-Kindy College Medical Journal (KCMJ)

Research Article

Artificial Intelligence-Based Prediction of Intra-Aortic Balloon Pump Need in High-Risk CABG Surgery: Enhancing Clinical Decision Support

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ABSTRACT

Background: In modern healthcare, decision-making processes are becoming increasingly data-driven, aiming to optimize patient care and resource allocation. Coronary artery bypass grafting (CABG) is a critical procedure for high-risk patients, and the use of intra-aortic balloon pump (IABP) assistance can significantly impact patient outcomes.
Objective: To identify preoperative factors that predict the need for IABP assistance in high-risk CABG patients and to develop a predictive model that can enhance clinical decision-making.
Subjects and Methods: The study involved fifty high-risk coronary artery bypass graft patients, with 24 cases necessitating intra-aortic balloon pump assistance and the rest not requiring it. Seven preoperative variables, including age, weight, ejection fraction, number of grafts, creatinine level, diabetic status, and blood pressure, were considered as potential predictors. SPSS was adopted to conduct a multi-variable regression analysis and derive the mathematical equations for the predictive model. A graphical user interface (GUI) was developed to utilize these equations for predicting the need for IABP support.
Results: The findings revealed a strong correlation among several preoperative factors and the likelihood of requiring IABP assistance. By employing the predictions from the model to guide preoperative intra-aortic balloon insertion, the potential for optimizing hemodynamic support during surgery was maximized.
Conclusions: This research emphasizes the importance of enhancing risk assessment techniques to empower medical specialists to tailor treatment plans to each patient's specific needs. Early identification of individuals at risk of requiring IABP can significantly enhance surgical outcomes and patient safety. Incorporating the predictive model into clinical practice allows for more individualized and effective care during high-risk CABG surgeries. This modern strategy has the potential to revolutionize cardiac outcomes, improve patient results, and extend the use of intra-aortic balloon support.

Article history:
Received 9 March 2024
Accepted 24 June 2024
Available online 1 August 2024

https://doi.org/10.47723/sf00fq21

Keywords: Intra-Aortic Balloon Pump, Coronary Artery Bypass Grafting, Predictive Model, Preoperative Data, Graphical User Interface, High-Risk Management.

Introduction

A technique that is frequent surgical for persons suffering increased coronary artery disease is coronary artery bypass grafting (CABG) (1) Taking that effective into account, some high-risk patients may need more support, like an intra-aortic balloon pump (IABP), in the event that they suffer from hemodynamic instability after surgery (2). Using IABP when necessary, may lead to an extensive impact on patient results and enhance convalescence after doing surgery (3). IABP is used to improve cardiac result by 10% to 30%, maintain myocardial viability, optimize oxygen supply-demand balance to minimize ischemia zone size, and in the short term sustain the left ventricle after cardiac failure after a myocardial infarction (4). After CABG, myocardial shock could possibly lead to postoperative heart failure in some persons. In these circumstances, the Intra-Aortic Balloon Pump (IABP) employed preoperatively and perhaps increase postoperative convalescence percentages (5). IABP significantly affected both the per-operative death rate (1.5%) and the post-operative need for vasoactive and inotropic medications in patients with EF less than 30% (6). Patients suffering from EF less than 30% had significantly more mortalities rate than patients with EF greater than 30% (7).

Moreover, systemic arterial hypertension is as a protective factor, whereas old age people and the period of the Cardio Pulmonary Bypass (CPB) were key risk factors (1). It is expected that gaining overweight or obesity will have a basic effect on the probability of enhancing coronary artery disease (CAD). There are novel strategies to detect how gaining weight increase the effects of cardiovascular surgeries, with a specific focus on the need for IABP support after CABG surgery (8). Owing to constructional shifts in the heart that take place with aging, cardiovascular disease becomes more widespread and increases functional needs. Age-related decreases in cardiac reserve lead to a less effective heart with limited capacity for repair (9).

Our study counts on the fraction of ejection, that is vital for assessing heart function. Patients having a considerably lower ejection fraction (EF) than those having a greater EF level are more likely to pass away after CABG (10). In this patient population, the insertion of IABP is a good indicator of longer hospital stays, higher 30-day death rates, and more surgical problems (6). Heart surgery results are significantly impacted by creatinine levels, which can increase hospitalization, ICU stay, and morbidity. Prior to heart surgery, a renal function evaluation is essential to determine the general health of the patient (11). Comprehending this possible association facilitates a more sophisticated evaluation of risk, assisting medical professionals in making knowledgeable choices about the application of IABP to enhance hemodynamic support (12).

Blood pressure's link to the need for IABP assistance is crucial in-patient management. Persistent hypertension leads to left ventricular hypertrophy, impairing both systolic and diastolic function and raising the risk of myocardial ischemia (13).

Diabetes is a serious chronic condition. Improper glycemic control, obesity, dyslipidemia, and hypertension are the traditional risk factors for developing any kind of cardiovascular disease in diabetics (14).

Artificial intelligence (AI) had a long and substantial history in healthcare, marked by important accomplishments. Alan Turing's launch of the idea in 1950, which included "Turing test" established the groundwork for the advancement of artificial intelligence (15). John McCarthy provided a more specific definition of AI in 1956, describing it as the field of study focused on developing intelligent machines (16).

Logistic regression is a statistical model that predicts the likelihood of an event happening based on a linear combination of predictor variables (17). By utilizing risk prediction models, doctors may rapidly identify patients who are at a heightened risk and subsequently implement vigilant monitoring and effective preventative and therapeutic interventions (18). Digital healthcare can improve therapeutic outcomes, reduce human error, track data across time, and other benefits (19).

In modern medical research, advanced statistical methods, such as IBM SPSS Statistics, are vital for analyzing complex data patterns (20). Aim of the study is to develop a risk model to identify high-risk patients and predict the need for IABP insertion during CABG. The accuracy and completeness of source databases are crucial in risk modeling. However, the problem of erroneous and missing data entry may be addressed by introducing extensive and continuous monitoring methods (21).

We acknowledge technology's crucial role in connecting advanced statistical methods with clinical practice, enhancing user-friendliness with a Graphical User Interface (GUI) integrated into IBM SPSS Statistics. The GUI simplifies SPSS complexities, enabling easy navigation and interaction with data, even for non-statisticians. Users can select various parameters effortlessly (22).

The simplified interface not only streamlines data input and comprehension but also seamlessly integrates our prediction model into routine clinical decisions. Research indicates that about 10% of medical procedures may lack medical necessity, subjecting patients to unnecessary risks without clinical benefits (23). Creating a dependable predictive model to identify high-risk CABG patients needing preoperative IABP support is vital for improving patient care. Recent 2023 research discovered that preemptive IABP usage prior to elective CABG notably decreased low cardiac output syndrome in stable patients with reduced LVEF. Additionally, it reduced the necessity for postoperative vasoactive and inotropic medications without inducing severe vascular complications (7).

Subjects and Methods

Study Design and Data Collection:

The current research was a retrospective observational analysis highlighted the examination of preoperative factors and their association with the requirement of IABP support in high-risk CABG procedures. Multivariable regression analysis was adopted that was leading to the derivation of 16 mathematical equations for predictive modeling. SPSS was used for making statistical analysis to process the relationships in the data. We studied fifty patients who had open-heart surgery, with 24 requiring IABP support. These equations offer detailed insight into variables affecting IABP necessity in cardiac surgery. Using multi-variable regression, we examined seven preoperative factors' connections to IABP need, resulting in sixteen tailored mathematical formulas.

To enable users to enter several data, such as age, weight, EF %, and creatinine levels, a (GUI) system was made. By using this kind of data, the GUI computes show the estimated probability that a balloon would be required during CABG operation.

The study was conducted at several various sites, such as Ibn Al-Bitar Cardiac Surgical Center, specialized in heart surgery, and the University of Al-Nahrain in Baghdad, Iraq, which has a department dedicated to bio-medical engineering.

Over the course of the 18-month experimentation, data taken from persons suffering CABG operations was collected and tested properly. IABP was adopted to search for probabilistic correlations among well-chosen variables. Each member had CABG surgery, and related

medical data was collected from various diagnostic tests, like blood tests measuring factors like creatinine levels and diabetes status, reports of percutaneous coronary intervention (PCI), and tests of echocardiogram to assess EF% and graft numbers.
Demographic characteristics such as weight, age, and blood pressure were uniformly measured one day before scheduled CABG procedures, ensuring a synchronized dataset for analysis. The objective is to find the intricate relationship between these factors and the necessity for IABP support during high-risk CABG procedures (refer to Figure 1).

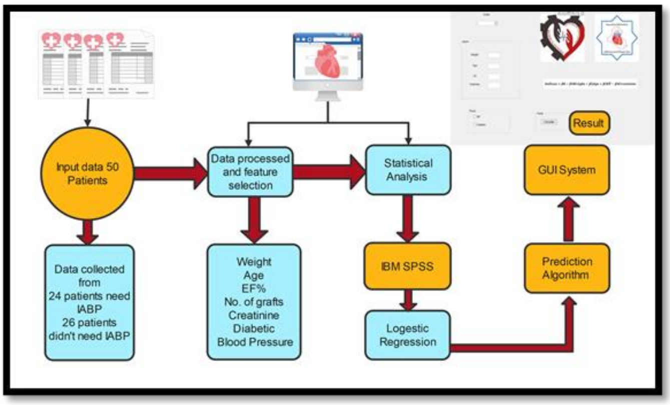

Figure 1: System Workflow

The study utilized (IBM SPSS 23) Statistics for multi-variable logistic regression analysis. This aimed to clarify connections between preoperative characteristics and the requiring IABP support during CABG surgeries. Logistic regression examines the impact of multiple independent variables on a binary dependent variable, producing an equation for prediction (24).
A seven carefully chosen factors, including weight, age, ejection fraction, and creatinine level as quantitative parameters, along with diabetes condition, blood pressure, and number of grafts as nominal measures, were incorporated into a binary logistic regression model to predict the need for IABP usage during CABG surgeries. This technique enables assessment of associations between the binary dependent variable (IABP usage) and each independent variable while considering the effects of others, facilitating extraction of significant insights and development of a robust mathematical model, the use of binary logistic regression enables the identification of significant predictors and the creation of a predictive model that can aid in clinical decision-making regarding the need for IABP assistance (11).
Binary logistic regression was used to convert the complex relationships within the data into a predictive model. The coefficients derived from this study served as the fundamental elements of a mathematical framework, revealing the general equation form:
$balloon = \beta0 + \beta1*Weight + \beta2*Age - \beta3*EF - \beta4*Creatinine$
Where:
$\beta0$, $\beta1$, $\beta2$, $\beta3$, and $\beta4$ are the coefficients for the intercept, weight, age, EF (ejection fraction), and creatinine, respectively. The coefficients represent the impact of each variable on the estimated chance of needing a balloon. Positive coefficients indicate a positive correlation, while negative coefficients indicate a negative correlation. Every equation corresponds to a distinct scenario determined by the number of grafts, blood pressure, and diabetes state. The graphical user interface (GUI) utilizes a simple framework that's accessible to users who do not have programming skills (as in figure 2). Users such as doctors, perfusionists, and nurses have an interest in uploading the patient's information and obtaining the prediction result immediately (25).

Figure 2: Graphical User Interface System

The" pushbutton_Calculate" function is performed when the user interacts with the "Calculate" button by pushing it. The system acquires the chosen values for the number of grafts, blood pressure, and diabetes conditions, in addition to the user-provided parameters. The provided inputs are used to compute the predicted probability of needing a balloon by employing a series of conditional equations. The outcome is thereafter shown in the edit results field.
Radio buttons allow users to indicate the patient's blood pressure and diabetes condition. The drop-down menu, named "popup_Grafts," enables users to choose the number of grafts, offering adjustability and suiting various surgical situations. Presenting pictures related to the study setting, such as the key equation, assists users in understanding the goal and context of the program. The users may easily identify the input fields, make choices, and view the outcomes

Results

Results were presented in odds ratios, with additional tests and receiver operating characteristic analysis to evaluate model performance and discrimination in cardiac surgery patients (26). To thoroughly investigate high-risk CABG patients, specifically examining the complex relationship between many preoperative characteristics and the probability of needing IABP assistance during operation.

Descriptive Statistics:

The descriptive statistics provide valuable insights into the correlations (in table1) between the requirement for IABP in CABG surgery and the following variables:

Weight: Mean: 86.68 kg, Standard Deviation: 10.55 kg, Minimum: 68.00 kg, Maximum: 105.00 kg.
Age: Mean: 62.98 years; Standard Deviation: 11.62 years; Minimum: 35 years; Maximum: 84 years.
EF (Ejection Fraction): Mean: 40.60%, Standard Deviation: 9.80%, Minimum: 20%, Maximum: 58%.
Creatinine: Mean: 1.0800 mg/dL, Standard Deviation: 0.4198 mg/dL, Minimum: 0.4000 mg/dL, Maximum: 2.2000 mg/dL.

Table 1: Groupe statistics

	balloon	N	Mean	Std. Deviation	Std. Error Mean
Weight	balloon needed	24	94.21	7.472	1.525
	no need for balloon	26	79.73	7.877	1.545
Age	balloon needed	24	65.83	13.605	2.777
	no need for balloon	26	60.35	8.899	1.745
EF%	balloon needed	24	32.1250	4.63740	.94660
	no need for balloon	26	48.4231	5.98112	1.17299
No. of grafts	balloon needed	24	3.25	.608	.124
	no need for balloon	26	2.77	.863	.169
Blood pressure	balloon needed	24	.92	.282	.058
	no need for balloon	26	.54	.508	.100
Diabetic	balloon needed	24	.83	.381	.078
	no need for balloon	26	.54	.508	.100
Creatinine	balloon needed	24	1.2571	.42570	.08690
	no need for balloon	26	.9165	.34753	.06816

The Hosmer-Lemeshow test is frequently employed to evaluate the adequacy of fit of logistic regression models. The test statistics in the output show that the model fits the data well. This is supported by a non-significant p-value (p = 0.653), which suggests that there is no significant difference between the observed and predicted values for different levels of the predictor variables. (As seen in table 2)

Table 2: Hosmer and Lemeshow Test

Step	Chi-square	df	Sig.
1	5.056	7	0.653

Table 3: Contingency Table for Hosmer and Lemeshow Test

	balloon= no need forballoon balloon		balloon= balloon needed		
	Observed	Expected	Observed	Expected	Total
1	5	4.998	0	.002	5
2	5	4.990	0	.010	5
3	5	4.961	0	.039	5
4	4	4.797	1	.203	5
5	4	3.305	0	.695	4
6	3	2.353	4	4.647	7
7	0	.359	5	4.641	5
8	0	.154	6	5.846	6
9	0	.082	8	7.918	8

The contingency table (see table3) presents a detailed analysis of the observed and predicted frequencies for each category of the predictor variable (specifically, "balloon = no need for balloon" and "balloon = balloon needed"). The table demonstrates a strong alignment between the observed frequencies and the anticipated frequencies at various levels, providing more evidence for the logistic regression model's goodness of fit.
Furthermore, the classification table displays the accuracy of the logistic regression model in accurately forecasting results. The graph displays the actual results compared to the projected results derived by the model. The table demonstrates that the model exhibits a substantial proportion of accurate forecasts for both categories ("no need for balloon" and "balloon needed"), resulting in an overall right classification rate of 94.0%.

Table 4: Classification Table

Observed		Predicted balloon no need balloon	forballoon needed	Percentage Correct
balloon	no need for balloon	25	1	96.2
	balloon needed	2	22	91.7
Overall Percentage				94.0

Based on the results of the Hosmer-Lemeshow test, contingency table, and classification table, it can be concluded that the logistic regression model is effective and accurately predicts the requirement for balloon insertion in high-risk CABG cases.

The prediction model was applied to several patients to determine the percentage of patients who would require IABP during CABG surgery. For a specific patient with the following characteristics: 2 grafts, weight of 75 kg, age of 36 years, EF% of 45%, creatinine level of 0.754, normal blood pressure, and no diabetes, the prediction percentage was determined to be 17.4% that this patient would require the balloon during the CABG surgery. Conversely, in the case of a patient undergoing 4 grafts, the patient weighed 95kg, was 58 years old, had an EF ratio of 30%, and a creatinine level of 1.23. Additionally, the patient had hypertension and diabetes. The findings indicated a 99.2% likelihood that the patient would require a post-operative balloon (as the figure 3 show).

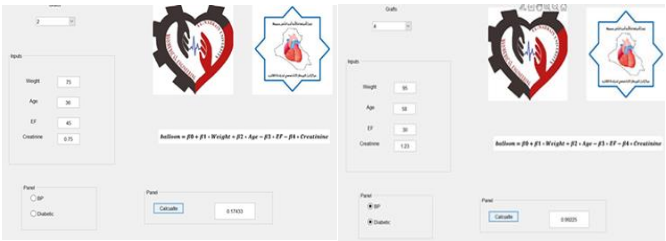

Figure 3: GUI with different patient's data

The first patient, with fewer risk factors and better overall health indicators, has a relatively low prediction percentage, while the second patient, with multiple risk factors including diabetes, hypertension, and poorer cardiac function, has a much higher prediction percentage. This demonstrates how predictive models can help assess individual patient risk and guide clinical decision-making. The graphical user interface (GUI) enables users to enter several factors, including weight, age, ejection fraction (EF), and creatinine level. Using these inputs, the GUI calculates and presents the estimated chance of requiring a balloon during the CABG procedure. The graphical user interface (GUI) offered instantaneous outcomes in the analysis.

Discussion

The outcomes of this study illuminate the intricate relationship between preoperative factors and the likelihood of requiring IABP assistance in high-risk CABG procedures. The analysis of coefficients emphasizes the pivotal role of each variable, establishing a foundation for clinical comprehension. Risk models are utilized in cardiac surgery for many purposes such as patient counseling, surgical decision-making, clinical study, quality monitoring as well as improvement, and financial compensation (21).

Examine some significant correlations and analyze their consequences (shown in Pearson correlation in table 2):
Weight and Balloon: correlation coefficient: 0.693; P-value: 0.000. Implication: There is a strong positive association between weight and the need for the "balloon". This implies that when the weight increases, there's a tendency for the "balloon" variable to also increase. This suggests a possible correlation between weight and the dependent variable.

EF% and Balloon: correlation coefficient: is -0.839; The P-value is 0.000. Implication: There appears to be a highly significant inverse relationship between the EF% and the "balloon" requirement. As the EF% decreases, there is a tendency for the "balloon" variable to rise. This finding has significant therapeutic implications, indicating that a decreased ejection fraction may be correlated with an increased probability of having the "balloon".

Correlation between Balloon and Creatinine Levels: The coefficient has a value of 0.409; The P-value is 0.003. Implication: There exists a direct relationship between the variable "balloon" and the levels of creatinine, with a positive correlation. This indicates that when the levels of creatinine rise, the probability of the occurrence of the "balloon" event also tends to rise. Increased levels of creatinine may suggest compromised kidney function, and this connection might have important medical consequences.

Correlation between Balloon and Age: The coefficient is 0.238; and the P-value is 0.096. Implication: The variable "balloon" is positively correlated with age, although this association is not statistically relevant at the standard significance threshold of 0.05. It indicates an inadequate correlation, necessitating more inquiry in order to determine whether age is a significant indicator of the "balloon" result.

Table 5: Pearson Correlation

		Weight	Age	EF%	Creatinine	balloon
Weight(kg)	Pearson Correlation	1	.293*	-.603**	.341*	.693**
	Sig. (2-tailed)		.039	.000	.015	.000
	N	50	50	50	50	50
Age(years)	Pearson Correlation	.293*	1	-.279*	.238	.238
	Sig. (2-tailed)	.039		.050	.096	.096
	N	50	50	50	50	50
EF%	Pearson Correlation	-.603**	-.279*	1	-.478**	-.839**
	Sig. (2-tailed)	.000	.050		.000	.000
	N	50	50	50	50	50
Creatinine(mg/dL)	Pearson Correlation	.341*	.238	-.478**	1	.409**
	Sig. (2-tailed)	.015	.096	.000		.003
	N	50	50	50	50	50
Balloon	Pearson Correlation	.693**	.238	-.839**	.409**	1
	Sig. (2-tailed)	.000	.096	.000	.003	
	N	50	50	50	50	50

The observed difference between the correlation and regression coefficients might be attributed to the inclusion of additional factors in the regression model. In a multiple regression model, the coefficients are computed while accounting for the influence of other variables.

It is crucial to analyze and understand the correlation and regression coefficients within the framework of this particular study. In contrast to the regression coefficient, which assesses the impact of one variable on another after adjusting for other model parameters, the correlation coefficient quantifies the strength and direction of the linear relationship between two variables.

Adopting SPSS Statistics and highly advanced statistical methods, we could make a collection of sixteen mathematical equations, each customized to cope with specific patient circumstances. Regression analysis was adopted to formulate such equations through allowing for the development of a prediction model to detect the need for IABP support in high-risk CABG patients. Varying combinations of preoperative attributes are represented by each equation, offering key information about the possibility of requiring IABP support during surgery. The weight needed for the "balloon" had a significant positive connection, suggesting that weight could be used as a predictor of the requirement for IABP support. However, the inverse correlation revealed among EF% and the "balloon" highlights how vital it is to include ejection fraction during doing preoperative evaluations. There could be a relationship between renal function and the requirement for IABP support if there is a positive correlation between levels of creatinine and renal function. Preoperative renal dysfunction (RD) is a common finding in patients suffering from CABG and is associated with significant prognostic implications. (27,28).

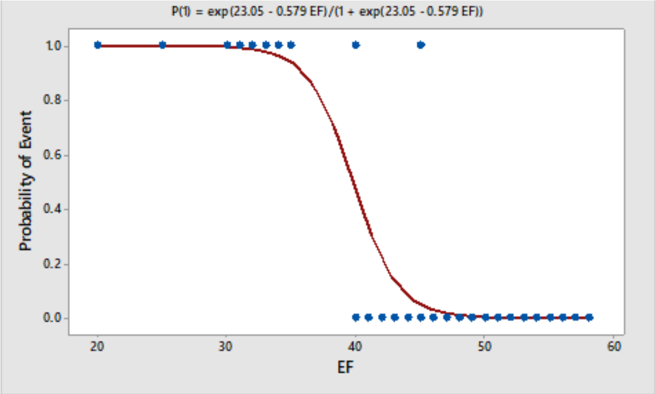

Figure 4: Binary Fitted Line of the EF%

The R-squared values in the model summary (see table 6) indicate a significant capacity to predict the outcome, with EF and weight playing a substantial role. The high R-squared value (79.09%) signifies that a great deal of the variation in the "balloon" variable can be ascribed to both factors. The adjusted R-squared, accounting for model complexity, providing a more careful evaluation at 74.27%.

Table 6: Model Summary

S	R-sq	R-sq(adj)
0.256217	79.09%	74.27%

Containing further variables in the model may increase its complexity, but it could possibly reveal extra factors contributing to IABP requirement. It could explore potential interaction effects among variables, like the integrated effect of weight and EF or the interaction among age and levels of creatinine, could provide detailed insights. Developing a graphical user interface (GUI) system contributes to usability and practicality of prediction model by enabling consumers to engage without learning complex statistical processes. This breakthrough improves clinical understanding of the interplay among preoperative variables and provides a better instrument for risk assessment and decision-making in the field of cardiac surgery.

Conclusion

The purpose behind this study was to enhance risk assessment and the assist the clinical decision-making by designing a model for prediction that could viably identify when high-risk CABG operations are required for IABP assistance. Through making use of multivariable regression analysis in SPSS, the research reached at a conclusion that there were significant correlations among the probability of requirements for IABP assistance and a number of preoperative factors, such as age, weight, ejection fraction, levels of creatinine, diabetes status, and blood pressure. The results revealed a clear correlation among weight and the necessity for IABP assistance, suggesting that weight may be a predictive factor. Instead, ejection fraction revealed a negative correlation, focusing on the significance of assessing heart function prior to surgery. Moreover, a significant correlation was noticed among the requirement for IABP and levels of creatinine, stressing the role of renal function in expecting hemodynamic instability. The prediction model made, that is composed of sixteen customized mathematical equations for various patient cases, had a high degree of predictive power, with weight and ejection fraction being shown to be basic variables. A Graphical User Interface was integrated to enhance usability and make it simpler for clinical practitioners to make some interaction with the model. Through the development of a beneficial instrument for individualized risk assessment and decision-making in high-risk CABG operations, our research advances the field of cardiac surgery. The predictive approach can enhance intra-aortic balloon support use, surgical results, and patient care. This study provides a major breakthrough in heart surgeries and safety of patient by integrating advanced statistical methodology into routine clinical practice through intuitive interfaces.

The study's limitations are that the sample size may be too small to generalize the findings of this research. Also, it was a single-center study where multi-center contributions could improve the predictive model. The selection of other variables, such as medication history, can be included and considered in future research. Addressing these limitations and considering them into account might improve the applicability of the research findings in clinical practice.

Funding

This research did not receive any specific fund.

Conflict of Interest

Authors declare no conflict of interest.

Data availability

Data are available upon reasonable request.

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To cite this article: Wajeeh ZA, Hamandi SJ, Al-Obaidi WS, Kervan U. Artificial Intelligence-Based Prediction of Intra-Aortic Balloon Pump Need in High-Risk CABG Surgery: Enhancing Clinical Decision Support. Al-Kindy College Medical Journal 2024;20(2):145-151. https://doi.org/10.47723/sf00fq21