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Long-Term Outcomes after Coronary Artery Bypass Grafting with Risk Stratification

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Abstract

Background: Risk stratification of long-term outcomes for patients undergoing Coronary artery bypass grafting has enormous potential clinical importance. **Aim:** To develop risk stratification models for predicting long-term outcomes following coronary artery bypass graft (CABG) surgery. **Methods:** We retrospectively revised the electronic medical records of 2330 patients who underwent adult Cardiac surgery between August 2016 and December 2022 at Madinah Cardiac Center, Saudi Arabia. Three hundred patients fulfilled the eligibility criteria of CABG operations with a complete follow-up period of at least 24 months, and data reporting. The collected data included patient demographics, comorbidities, laboratory data, pharmacotherapy, echocardiographic parameters, procedural details, postoperative data, in-hospital outcomes, and follow-up data. Our follow-up was depending on the clinical status (NYHA class), chest pain recurrence, medication dependence and echo follow-up. A univariate analysis was performed between each patient risk factor and the long-term outcome to determine the preoperative, operative, and postoperative factors significantly associated with each long-term outcome. Then a multivariable logistic regression analysis was performed with a stepwise, forward selection procedure. Significant ($p < 0.05$) risk factors were identified and were used as candidate variables in the development of a multivariable risk prediction model. **Results:** The incidence of all-cause mortality during hospital admission or follow-up period was 2.3%. Other long-term outcomes included all-cause recurrent hospitalization (9.8%), recurrent chest pain (2.4%), and the need for revascularization by using a stent in 5 (3.0%) patients. Thirteen (4.4%) patients suffered heart failure and they were on the maximum anti-failure medications. The model for predicting all-cause mortality included the preoperative EF ≤ 35% (AOR: 30.757, p = 0.061), the bypass time (AOR: 1.029, p = 0.003), and the duration of ventilation following the operation (AOR: 1.237, p = 0.021). The model for risk stratification of recurrent hospitalization comprised the preoperative EF ≤ 35% (AOR: 6.198, p < 0.001), having left main disease (AOR: 3.386, p = 0.023), low postoperative cardiac output (AOR: 3.622, p = 0.007), and the development of postoperative atrial fibrillation (AOR: 2.787, p = 0.038). Low postoperative cardiac output was the only predictor that significantly contributed to recurrent chest pain (AOR: 11.66, p = 0.004). Finally, the model consisted of low postoperative cardiac output (AOR: 5.976, p < 0.001) and postoperative ventricular fibrillation (AOR: 4.216, p = 0.019) was significantly associated with an increased likelihood of the future need for revascularization using a stent. **Conclusions:** A risk prediction model was developed in a Saudi cohort for predicting all-cause mortality risk during both hospital admission and the follow-up period of at least 24 months after isolated CABG surgery. A set of models were also developed for predicting long-term risks of all-cause recurrent hospitalization, recurrent chest pain, heart failure, and the need for revascularization by using stents.

Keywords

Coronary Artery Bypass Graft, Long-Term Mortality, Risk Prediction Model, Risk Stratification

1. Introduction

Coronary artery bypass grafting (CABG) surgery is the most common heart surgery worldwide. CABG remains the gold standard to treat obstructive coronary artery disease in patients with a high risk for extensive ischemic cardiomyopathy [1].

Over the last few decades, there were progresses in surgical technologies and perioperative care, which have been associated with decreased operative risk of CABG. The reported in-hospital mortality and 30-day mortality rates have improved [2] [3]. However, these short-term outcomes do not provide satisfactory information to monitor long-term patient management following the surgery [4]. Therefore, assessment of long-term survival and quality of life following cardiac surgery have received more concern nowadays. Another aspect that favors developing specific models for predicting long-term outcomes following CABG is the fluctuating impact of predictor variables on mortality with the increase in time passing following surgery [5].

The development of long-term risk prediction models specifically related to perioperative factors, including preoperative data combined with intra- and postoperative parameters, would enable the identification of patients with a poor prognosis [6]. This would essentially help in selecting patients who would benefit considerably from CABG surgery. Moreover, patients, interventional cardiologists, and cardiac surgeons can implement behavioral and therapeutic modifications to optimize the benefit of surgery [7].

It has been reported that a risk prediction model will generally predict outcomes more accurately in the population setting where it was originally developed. Previous long-term prediction models have been developed in the USA [8] [9] [10]. Australia [11], and China [12] but no models are currently available for predicting long-term outcomes following CABG surgery in Saudi patients. Therefore, this study aimed to develop risk stratification models for predicting long-term outcomes following CABG surgery among a cohort of Saudi patients.

2. Methods

2.1. Ethical Considerations

The study was conducted following the principles of Good Clinical Practice and the Declaration of Helsinki, and its research protocol was approved by the Institutional Review Board of General Directorate of Health Affairs in Madinah, Saudi Arabia (ID: 23-047) The requirement for informed consents was waived because of the nature of the study. The final database used for statistical analysis was anonymous with a code number for every patient.

2.2. Study Design, Settings, and Duration

This single-center, registry-based, retrospective cohort study included consecutive patients who underwent isolated CABG surgery between August 2016 and December 2022 at Madinah Cardiac Center, Saudi Arabia.

2.3. Eligibility Criteria

Inclusion criteria:

- Elective or emergency isolated CABG operation.
- Patient with regular follow-up over at least 24 months post-operative.

Exclusion criteria:

- Patients who underwent concomitant operation with CABG.
- Patient who lost follow-up post-operative or his follow up period less than 24 months.
- Died early post-operative or before 2 years follow up.

2.4. Data Collection

We retrospectively revised the electronic medical records of 2330 patients who underwent adult Cardiac surgery during the study duration. Three hundred patients fulfilled the eligibility criteria with complete data reporting. The collected data included patient demographics, comorbidities, laboratory data, pharmacotherapy,

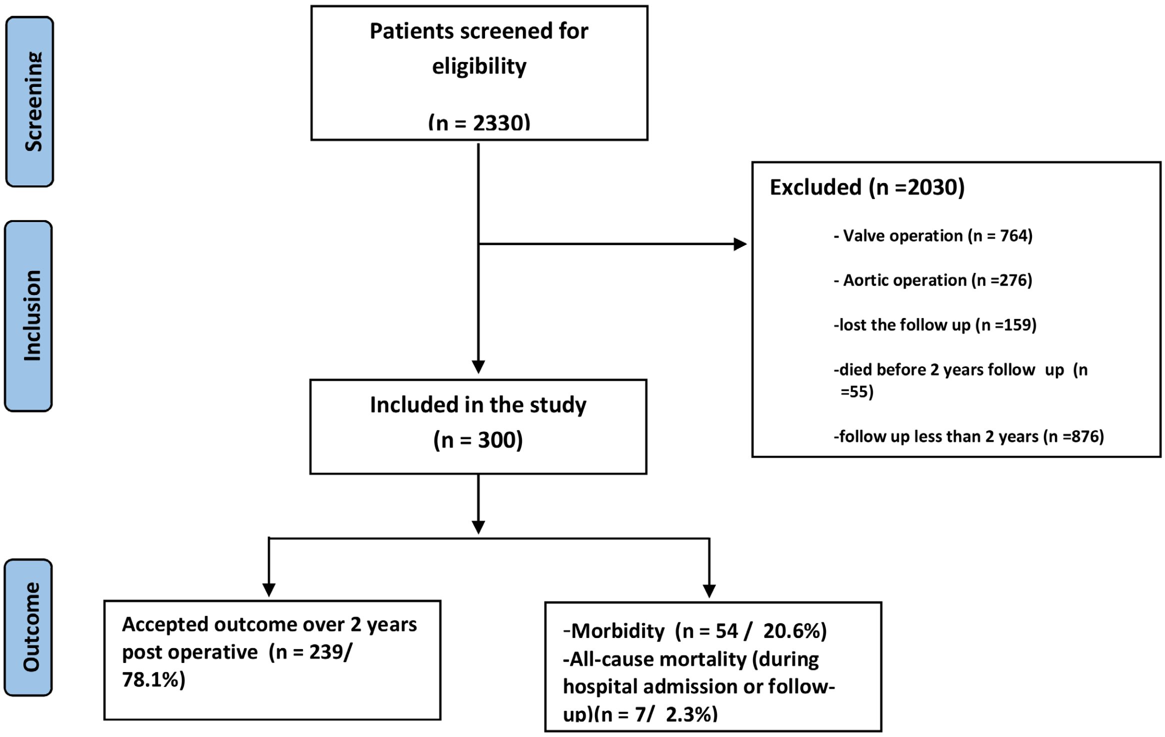

Figure 1. Patient selection flow chart.

echocardiographic parameters, procedural details, postoperative data, in-hospital outcomes, and follow-up data.

2.5. Surgical Procedure

The CABG on cardiopulmonary bypass procedure is a standard technique in our institution. The procedures were performed from full median sternotomy. The left internal mammary artery and great saphenous vein are the standard conduits used except in emergency patients where we used just the great saphenous vein. The grafts were harvested, and intravenous heparin was administered to achieve the desired activated clotting time of 420- ± 40 s. The anastomoses were performed by running a 7 - 0 monofilament prolene suture.

2.6. Follow-Up

All patients' follow-up was through routine outpatient clinic visits via complete clinical assessment, ECG, or Echocardiography depending on the primary clinical status. During the COVID-19 era, the follow-up was through telephone calls or virtual clinics (patient effort and dyspnea status, medication dependence, daily activity) and if the patient needs critical assessment we arranged program for home visit. The follow-up pattern was 1 and 3 months after surgery and every 6 months thereafter.

2.7. Outcomes

The long-term outcomes included the incidence of all-cause mortality during the hospital admission or the follow-up period, recurrent hospitalization for chest pain, heart failure, or rehabilitation, recurrent chest pain, heart failure, and the need for revascularization using a stent.

2.8. Statistical Analysis

All data were tabulated and analyzed by the statistical package for social sciences software program, IBM SPSS Statistics for Windows, version 26 (IBM Corp., Armonk, N.Y., USA). Continuous variables were reported as mean ± standard deviation (SD) or median with interquartile range and were compared using an unpaired t-test or Mann-Whitney U test, depending on the normality of the distribution. Categorical variables were reported as frequencies and percentages and were compared using Chi-Square or Fisher's exact tests as appropriate. Furthermore, the Marginal homogeneity test was applied to compare the preoperative and the postoperative NYHA classes. A univariate analysis was performed between each patient risk factor and the long-term outcome to determine the preoperative, operative, and postoperative factors significantly associated with each long-term outcome. Then a multivariable logistic regression analysis was performed with a stepwise, forward selection procedure. Significant ($p < 0.05$) risk factors were identified and were used as candidate variables in the development of a multivariable risk prediction model. The obtained results are presented as adjusted odds ratios (AOR) to the coexistence of other predictors and their 95% confidence intervals (CI).

Patient risk factors examined were preoperative data including demographics, body mass index (BMI), nature of the procedure whether elective or emergency, preoperative New York Heart Association (NYHA) class, European System for Cardiac Operative Risk Evaluation (Euro SCORE II), preoperative ejection fraction (EF) (≤35% or not), Serum creatinine, current smoking, dyslipidemia, diabetes mellitus, hypertension, hypothyroidism, cerebrovascular accident (CVA), peripheral vascular disease (PVD), chronic obstructive pulmonary disease (COPD), unstable angina, and left main (LM) coronary disease, operative data were the number of grafts, and bypass and cross-clamp times, while the postoperative data comprised duration of ventilation, postoperative EF (≤35% or not), pneumonia, sepsis, postoperative cerebrovascular accident, renal dialysis, postoperative low cardiac output, postoperative atrial and ventricular fibrillation, deep sternal wound infection, and the total hospital stay. A p-value < 0.05 was considered statistically significant.

3. Result

This study included 300 cardiac patients who underwent isolated CABG surgery and completed follow-ups for at least 24 months. Their mean age was 60.1 ± 9.0 years and males (87.0%) outnumbered females. The median BMI was 28.0 (IQR: 26.7 - 30.0). In 253 (84.3%), the operation was elective while it was urgent in 15.7%. The preoperative NYHA classes were class 1 (30.3%), class 2 (29.7%), class 3 (35.7%), and class 4 (4.3%). The mean preoperative Euro SCORE II was 1.84 ± 0.69 and 23.7% had preoperative EF of ≤35%. More than half (51%) were current smokers. The associated morbidities included dyslipidemia (50.3%), diabetes mellitus (71.0%), hypertension (70.3%), hypothyroidism (9.3%), recent cerebrovascular accident (5.3%), peripheral vascular disease (10.7%), and COPD (7.7%). 132 (44.0%) has unstable angina and (11.7%) had left main (LM) coronary disease. The surgical procedures had a median BP time of 88.5 (IQR: 70.0 - 110.0) minutes, a median C-Clamp time of 38.5 (IQR: 25.0 - 55.5) minutes, and a mean number of grafts of 2.7 ± 0.7. The median duration of ventilation was 3.0 (IQR: 3.0 - 5.0), the mean postoperative EF was 45.5 ± 9.3, and 60 (20.0%) has a postoperative low cardiac output. The postoperative NYHA classes were class 1 (69.0%), class 2 (23.0%), and class 3 (8%). Postoperative AF and VF were recorded in 16.3% and 6%, respectively. Postoperative complications included pneumonia (6.0%), sepsis (4.7%), deep sternal wound infection (18.3%), and CVA (2.7%). Sixteen patients (5.3%) required renal dialysis. The median duration of hospital stay was 9.0 (IQR: 7.0 - 12.0) days, and the duration of follow-up ranged from 24 to 52 with a median of 29.0 (IQR 27.0 - 34.0) months (**Table 1**).

Table 2 shows that the incidence of in-hospital mortality was 1.3% while the rate of all-cause mortality during hospital admission or follow-up period was 2.3%. Other long-term outcomes included recurrent hospitalization for chest pain, heart failure, or rehabilitation in 29 (9.8%) patients, recurrent chest pain (2.4%), and the need for revascularization by using a stent in 5 (3.0%) patients. Two patients needed a stent of the left circumflex, another two patients needed stenting of the left anterior descending, while stenting of the right circumflex was done in one patient. During the follow-up period, 13 (4.4%) patients suffered heart failure and they were on the maximum anti-failure medications.

The univariate binary logistic regression analysis for the risk of all-cause mortality following CABG during the hospital admission or the follow-up period showed some significant risk factors including urgent CABG (OR: 7.752, $p = 0.009$), Euro SCORE II (OR: 9.749, $p < 0.001$), a preoperative EF ≤ 35% (OR: 21.046, $p = 0.005$), bypass time (OR: 1.039, $p < 0.001$), the number of grafts (OR: 3.575, $p = 0.026$), duration of ventilation (OR: 1.194, $p = 0.001$), a postoperative EF ≤ 35% (OR: 12.150, $p = 0.003$), sepsis (OR: 9.367, $p = 0.012$), renal dialysis (OR: 7.971, $p = 0.018$), a low postoperative cardiac output (OR: 26.556, $p = 0.003$), postoperative VF (OR: 6.925, $p = 0.027$), and the length of hospital stay (OR: 1.072, $p = 0.001$) (**Table 3**).

The multivariable forward stepwise logistic regression analysis revealed a risk stratification model for the risk of death due to any cause following CABG during the hospital admission or the follow-up period of 52 months. The model had an accuracy of 97.7% and included the preoperative EF ≤ 35% (AOR: 30.757, $p = 0.061$), the BP time (AOR: 1.029, $p = 0.003$), and the duration of ventilation following the operation (AOR: 1.237, $p = 0.021$) (**Table 4**).

Table 5 shows a Risk stratification models for the other long-term. The model for risk stratification of recurrent hospitalization showed an accuracy of 91.5%

Table 1. Preoperative, operative, and postoperative characteristics of the studied patients (N = 300).

Age, Years	Mean ± SD	60.1 ± 9.0
Sex (Male)	N, %	261 (87.0%)
BMI, kg/m^2	Median (IQR)	28.0 (26.7 - 30.0)
Elective CABG	N, %	253 (84.3%)
Urgent CABG	N, %	47 (15.7%)
Preoperative NYHA Class 1	N, %	91 (30.3%)
Preoperative NYHA Class 2	N, %	89 (29.7%)
Preoperative NYHA Class 3	N, %	107 (35.7%)
Preoperative NYHA Class 4	N, %	13 (4.3%)
Euro SCORE II	Mean ± SD	1.84 ± .69
Preoperative EF %	Mean ± SD	44.3 ± 9.8
Preoperative EF % ≤ 35%	N, %	71 (23.7%)
Preoperative EF % > 35%	N, %	229 (76.3%)
Serum Creatinine	Median (IQR)	90.8 (80.0 - 108.0)
Current Smoking	N, %	153 (51.0%)
Dyslipidemia	N, %	151 (50.3%)
Diabetes Mellitus	N, %	213 (71.0%)
Hypertension	N, %	211 (70.3%)
Hypothyroidism	N, %	28 (9.3%)
Recent CVA	N, %	16 (5.3%)
PVD	N, %	32 (10.7%)
COPD	N, %	23 (7.7%)
Unstable Angina	N, %	132 (44.0%)
LM Disease	N, %	35 (11.7%)
BP Time/Min	Median (IQR)	88.5 (70.0 - 110.0)
C-Clamp Time/Min	Median (IQR)	38.5 (25.0 - 55.5)
Number of Grafts	Mean ± SD	2.7 ± 0.7
Duration of Ventilation, Days	Median (IQR)	3.0 (3.0-5.0)
Postoperative EF %	Mean ± SD	45.5 ± 9.3
Pneumonia	N, %	18 (6.0%)
Sepsis	N, %	14 (4.7%)
Postoperative CVA	N, %	8 (2.7%)
Renal Dialysis	N, %	16 (5.3%)
Postoperative Low Cardiac Output	N, %	60 (20.0%)

Continued

Postoperative AF	N, %	49 (16.3%)
Postoperative VF	N, %	18 (6.0%)
Postoperative NYHA Class 1	N, %	207 (69.0%)
Preoperative NYHA Class 2	N, %	69 (23.0%)
Preoperative NYHA Class 3	N, %	24 (8%)
Deep Sternal Wound Infection	N, %	55 (18.3%)
Total Hospital Stay, Days	Median (IQR)	9.0 (7.0 - 12.0)
Duration of Follow-Up, Months	Median (IQR)	29.0 (27.0 - 34.0)

AF: atrial fibrillation, BMI: body mass index, BP time: bypass time, C-clamp time: cross-clamp time, CABG: coronary artery bypass grafting, CVA: cerebrovascular accident, COPD: chronic obstructive pulmonary disease, Euro SCORE II: European System for Cardiac Operative Risk Evaluation, EF: ejection fraction, LM: left main, PVD: peripheral vascular disease, NYHA: New York Heart Association, VF: ventricular fibrillation, Min: minute, SD: standard deviation, IQR: interquartile range.

Table 2. In-hospital mortality and long-term outcomes of the studied patients throughout the follow-up period of 52 months.

In- Hospital Mortality	No	296	98.7%
	Yes	4	1.3%
All-Cause Mortality (During Hospital Admission or Follow-Up)	No	293	97.7%
	Yes	7	2.3%
Recurrent Hospitalization for Chest Pain, Heart Failure, or Rehabilitation	No	267	90.2%
	Yes	29	9.8%
Recurrent Chest Pain	No	289	97.6%
	Yes	7	2.4%
Heart Failure (On Maximum Anti-Failure Medications)	No	283	95.6%
	Yes	13	4.4%
Need for Revascularization (Stenting)	No	287	97.0%
	Yes	5	3.0%
Stent LCX		2	0.7%
Stent LAD		2	0.7%
Stent RCA		1	0.3%

LCX: left circumflex artery, LAD: left anterior descending artery, RCA: right coronary artery.

The variables that contributed significantly to the model comprised the preoperative EF ≤ 35% (AOR: 6.198, $p < 0.001$), having LM disease (AOR: 3.386, $p = 0.023$), low postoperative cardiac output (AOR: 3.622, $p = 0.007$), and the development of postoperative AF (AOR: 2.787, $p = 0.038$). Concerning the recurrent

Table 3. Univariate binary logistic regression analysis for the risk of all-cause mortality following CABG during the follow-up period of 52 months.

Parameters	Odds Ratio	95% CI	p-Value
Age, Years	0.981	0.903 - 1.066	0.657
Female Sex	1.118	0.131 - 9.547	0.919
BMI, kg/m^2	0.965	0.804 - 1.158	0.705
Urgent CABG	7.752	1.676 - 35.854	0.009*
Preoperative NYHA Class 2	1.023	0.063 - 16.607	0.987
Preoperative NYHA Class 3	3.495	0.384 - 31.844	0.267
Preoperative NYHA Class 4	7.500	0.440 - 127.920	0.164
Euro SCORE II	9.749	2.816 - 33.754	<0.001*
Preoperative EF ≤ 35%	21.046	2.489 - 177.964	0.005*
Serum Creatinine	1.008	0.998 - 1.018	0.109
Current Smoking	0.994	0.672 - 1.471	0.975
Dyslipidemia	1.324	0.480 - 6.060	0.716
Diabetes Mellitus	1.476	0.926 - 2.351	0.997
Hypertension	1.056	0.201 - 5.547	0.949
Hypothyroidism	1.200	0.817 - 1.762	0.998
Recent CVA	3.089	0.268 - 27.320	0.311
PVD	3.507	0.652 - 18.867	0.144
COPD	0.543	0.221 - 1.334	0.998
Unstable Angina	0.939	0.632 - 1.395	0.951
LM Disease	0.621	0.288 - 1.338	0.994
BP time/Min	1.039	1.022 - 1.056	<0.001*
C-Clamp time/Min	1.010	0.992 - 1.034	0.435
Number of Grafts	3.575	1.138 - 11.228	0.026*
Duration of Ventilation, Days	1.194	1.073 - 1.327	0.001*
Postoperative EF ≤ 35%	12.150	2.292 - 64.403	0.003*
Pneumonia	2.706	0.308 - 23.428	0.369
Sepsis	9.367	1.646 - 53.658	0.012*
Postoperative CVA	6.810	0.721 - 64.340	0.094
Renal Dialysis	7.971	1.420 - 44.760	0.018*
Postoperative Low Cardiac Output	26.556	3.132 - 225.144	0.003*
Postoperative AF	1.236	0.914 - 1.671	0.998
Postoperative VF	6.925	1.246 - 38.573	0.027*
Deep Sternal Wound Infection	0.881	0.523 - 1.484	0.634
Total Hospital Stay, Days	1.072	1.027 - 1.118	0.001*

AF: atrial fibrillation, BMI: body mass index, BP time: bypass time, C-clamp time: cross-clamp time, CABG: coronary artery bypass grafting, CVA: cerebrovascular accident, COPD: chronic obstructive pulmonary disease, Euro SCORE II: European System for Cardiac Operative Risk Evaluation, EF: ejection fraction, LM: left main, PVD: peripheral vascular disease, NYHA: New York Heart Association, VF: ventricular fibrillation, Min: minute, HR: hazard ratio, CI: confidence interval, *Significant at $p < 0.05$.

Table 4. A multivariable forward stepwise logistic regression model for the risk of death following CABG during the follow-up period of 52 months.

Parameters	Beta Coefficient	p-Value	AOR	95% CI of AOR		Accuracy	p-Value
				Lower	Upper		
Preoperative EF ≤ 35%	3.426	0.061	30.757	0.857	1103.606	97.7%	<0.001*
BP Time/Min	0.029	0.003*	1.029	1.010	1.049		
Duration of Ventilation, Days	0.213	0.021*	1.237	1.032	1.483		
Constant	−11.217	<0.001*					

CABG: coronary artery bypass grafting, EF: ejection fraction, AOR: adjusted odds ratio, CI: confidence interval, *significant at p < 0.05.

Table 5. Multivariable forward stepwise logistic regression models for the risk of recurrent hospitalization, recurrent chest pain, and heart failure on maximum anti-failure therapy.

Parameters	p-Value	AOR	95% CI		Accuracy	p-Value
			Lower	Upper		
Recurrent Hospitalization						
LM Disease	0.023*	3.386	1.187	9.711	91.5%	<0.001*
Postoperative Low Cardiac Output	0.007*	3.622	1.387	9.461		
Postoperative AF	0.038*	2.787	1.030	7.538		
Preoperative EF ≤ 35%	<0.001*	6.198	2.504	15.342		
Constant	0.303	2.812				
Recurrent Chest Pain						
Postoperative Low Cardiac Output	0.004*	11.66	2.202	61.819	97.6%	0.002*
Constant	<0.001*	0.008				
Heart Failure on Maximum Anti-Failure Therapy						
Postoperative EF ≤ 35%	<0.001*	11.271	3.261	38.957	95.6%	<0.001*
Postoperative AF	0.028*	3.881	1.156	13.030		
Constant	<0.001*	0.012				
Revascularization Using Stent						
Postoperative low Cardiac Output	<0.001*	5.976	2.610	13.684	90.2%	<0.001*
Postoperative VF	0.019*	4.216	1.271	13.986		
Constant	<0.001*	0.052				

AOR: adjusted odds ratio, CI: confidence interval, EF: ejection fraction, AF: atrial fibrillation, VF: ventricular fibrillation, LM: left main, *significant at p < 0.05.

chest pain, low postoperative cardiac output was the only predictor that significantly contributed to it (AOR: 11.66, p = 0.004), with an accuracy of 97.6%. The model consisted of low postoperative cardiac output (AOR: 5.976, p < 0.001) and postoperative VF (AOR: 4.216, p = 0.019) was significantly associated with increased likelihood of the future need for revascularization using stent with an accuracy of 90.2%. Further, patients with a postoperative EF ≤ 35% showed 11.271 times increased likelihood of developing heart failure (AOR: 11.271, p < 0.001), and the development of postoperative AF was significantly associated with an increased chance of the occurrence of heart failure (AOR: 3.881, p = 0.028).

There was a significant difference between the preoperative and the postoperative NYHA classes. Among the 91 patients who had preoperative NYHA class 1, 71 patients showed the same postoperative NYHA class while 20 patients showed upgrading to NYHA Class 2, or 3 (10 patients each). Among the 89 patients who had preoperative NYHA class 2, 52 patients showed downgrading to Class 2, 29 patients showed no change, and 8 patients showed upgrading to Class 3. Among the 107 patients who had preoperative NYHA Class 3, 77 patients showed a downgrading to Class 1, 25 patients downgraded to Class 2, and 5 patients showed the same class. All 13 patients who had preoperative NYHA Class 4 showed downgrading to Class 1 (7), Class 2 (5), or Class 3 (1) as illustrated in Table 6.

4. Discussion

Long-term duration of follow-up helps the clinical data registries for being realized as the delayed postoperative deaths would be captured and registered. Hence, it enables the comparison of the effectiveness studies of various treatment strategies for coronary artery disease. Moreover, some preoperative risk factors may have little impact on short-term mortality but are major considerations in the longer term, and vice versa. Knowledge of long-term health expectations effectively supports the shared decision-making of the patients with their providers and enables optimal treatment planning, and quality improvement initiatives [8] [12].

This study assessed the long-term impact of preoperative risk factors, operative

Table 6. Comparison of the preoperative and postoperative NYHA class in the studied patients (N = 300).

		Postoperative NYHA Class								Marginal Homogeneity Test p-Value
		1		2		3		Total		
		N	%	N	%	N	%	N	%	
Preoperative NYHA Class	1	71	23.7%	10	3.3%	10	3.3%	91	30.3%	<0.001*
	2	52	17.3%	29	9.7%	8	2.7%	89	29.7%	
	3	77	25.7%	25	8.3%	5	1.7%	107	35.7%	
	4	7	2.3%	5	1.7%	1	0.3%	13	4.3%	
	Total	207	69.0%	69	23.0%	24	8.0%	300	100.0%	

NYHA: New York Heart Association, *significant at p < 0.05.

and perioperative care processes, and postoperative complications on the CABG mortality, readmissions, and re-intervention outcomes of the patients who underwent isolated CABG surgery.

The rate of all-cause mortality during hospital admission or follow-up period was 2.3%. Four patients died during hospital admission (this early outcome) and three patients during the follow-up period (long term). This is much lower than the reported death rates of 1.7% at 90 days, 2.8% at 1 year, 4.4% at 2 years, and 6.1% at 3 years by Karim, *et al.* [11] in an Australian patient cohort.

Low preoperative ejection fraction (≤35%) and prolonged BP times and ventilation duration showed a significant negative impact on survival throughout hospital admission or at any time during the follow-up period. These candidate risk factors can predict death due to any cause following CABG during the hospital admission or the follow-up period of 52 months with an accuracy of 97.7%. Therefore, careful preoperative patient selection and operative monitoring, and perioperative management are essential for better survival in patients undergoing CABG. The low preoperative EF (≤35%) is an early predictor of death and it showed the highest risk (AOR: 30.757, $p = 0.061$). Since preoperative EF is a patient characteristic that is readily available before the operation, surgeons can rely on it to anticipate long-term prognosis for surgical decision-making.

Patients with low EF secondary to ischemic cardiomyopathy are considered a vulnerable patient population who requires preoperative optimization with mechanical circulatory support devices, especially in the setting of hemodynamic instability, to reduce morbidity and mortality [13].

Karim, *et al.* [11] found that reduced EF was associated with both short-term mortality and long-term mortality following CABG; reduced EF appeared as a significant predictor in all long-term models developed at 1, 2, and 3 years following CABG as well as in the 30-day mortality model reported in Euro-SCORE II.

An earlier study found that long-term survival was significantly decreased in patients with EF of 0.30 or less: 1-year survival was significantly reduced from 96% to 88% and the 5-year survival was reduced from 81% to 75% [14]. Another study in India found that lack of improvement of left ventricular function was a strong predictor of late mortality (odds ratio 25.20; CI 5.40 - 117.55) in patients with severe left ventricular dysfunction (ejection fraction ≤ 35%) who underwent CABG after a median follow-up period of 1057 days [15]. Congestive heart failure has been reported as a risk factor that significantly influences the prognosis of patients after CABG [16], and it was included in the nomogram for predicting the three-year mortality following CABG [12].

The improved mortality risks and prolonged survival times among patients who undergo CABG surgery emphasize the need to predict the risk of other long-term clinical outcomes. The determination of the preventable risk factors for hospital readmissions after CABG surgery is an important priority. The identification of high-risk population for repeated admissions after CABG provide a basis for stratified management and intervention of patients with different degrees of risk, which will help to maximize the effectiveness of treatment and reduce medical costs [17], Hence, this study explored the incidence of recurrent hospitalization due to chest pain, heart failure, or rehabilitation in 29 (9.8%) patients.

Some risk factors contributed significantly to a prediction model of the repeated all-cause hospital admission including two preoperative factors; preoperative EF ≤ 35% (AOR: 6.198, $p < 0.001$), having LM artery disease (AOR: 3.386, $p = 0.023$), and two postoperative factors; low postoperative cardiac output (AOR: 3.622, $p = 0.007$), and the development of postoperative AF (AOR: 2.787, $p = 0.038$). In comparison, a corresponding study reported that 9.15% of patients who underwent CABG were readmitted within 30 days, and there were five risk factors for the 30-day all-cause readmission: including age, previous heart failure, total preoperative albumin levels, previous myocardial infarction, and history of diabetes mellitus [18].

Furthermore, Sah, *et al.* [19] reported 12.2% readmissions within 30 days of discharge after CABG and atrial fibrillation (OR: 1.20) were among the significant risk factors. A retrospective cohort study at King Abdulaziz Medical City included adult patients who underwent CABG confirmed a 30-day readmission rate of 16.1%, and the readmission was associated with diabetes mellitus, asthma, hyperlipidemia, and use of medications such as amiodarone, statins, and amlodipine [20].

In this study, follow-up of the patients for at least 24 months revealed a 2.4% incidence of recurrent chest pain, and the postoperative low cardiac output was the only risk factor that significantly contributed to its prediction (AOR: 11.66, $p = 0.004$), with an accuracy of 97.6%. Furthermore, 5 (3.0%) patients needed revascularization by using a stent. Two patients needed a stent of the left circumflex; another two patients needed stenting of the left anterior descending, while stenting of the right circumflex was done in one patient. The risk stratification model for revascularization consisted of postoperative low cardiac output (AOR: 5.976, $p < 0.001$) and postoperative ventricular fibrillation (AOR: 4.216, $p = 0.019$), with an accuracy of 90.2%.

It is well established that the long-term efficacy of CABG is hindered by bypass graft failure and the progression of the original coronary artery disease, resulting in late recurrent angina. There was an 18% incidence of recurrent angina symptoms and ischemia at 5 years after CABG, which increased to 40% - 50% at 10 years and up to 60% at 15 years following the operation [21].

The long-term graft patency is related to the types of vascular conduits. The left internal mammary artery (and great saphenous veins are the standard Conduits used in this study. internal mammary artery grafts demonstrated excellent patency rates between 85 and 91% 10 years after CABG [22]. Saphenous vein graft failure has been reported between 10 and 20% within 1 year after CABG, with an additional yearly failure rate of 1% - 2% between 1 and 6 years [23].

Many patients who underwent CABG go through repeated cardiac catheterization and necessitate consequent revascularization therapy [24] [25]. It is essential to note that the distinction between recurrent chest pain due to angina from other causes of chest pain requires investigations and imaging studies of the heart [21].

It has been reported that heart failure is the most frequent cause of unscheduled hospital admission [26]. Accordingly, identifying patients at high risk has imperative implications for preventive efforts. During the follow-up period in the present study, 13 (4.4%) patients suffered heart failure and they were on the maximum anti-failure medications. Further, patients with a postoperative EF ≤ 35% showed 11.271 times increased likelihood of developing heart failure (AOR: 11.271, $p < 0.001$), and the development of postoperative AF was significantly associated with an increased chance of the occurrence of heart failure (AOR: 3.881, $p = 0.028$).

Much higher risk of heart failure after CABG has been reported by Teo, *et al.* [27] who found that 10% of the patients had at least one episode of heart failure hospitalization during a mean follow-up of 3.3 years, and by Moreyra, *et al.* [28] who detected 19% incidence of heart failure hospitalization at 2 years after CABG. The difference in the rates of heart failure risk is attributed to the different risk profiles of the patients. Furthermore, Moreyra, *et al.* [28] concluded that pre-operative EF is a strong predictor of heart failure admission within 2 years after CABG surgery. Furthermore, in this study, atrial fibrillation was another risk factor for heart failure (AOR: 3.881, $p = 0.028$). This is supported by those who concluded that atrial fibrillation is the most frequently occurring arrhythmic complication after CABG and it may contribute to mortality, and morbidity, and extends the ICU stay [29].

Another important finding in the present study is the improvement of NYHA classes following the CABG where more patients who had classes 3 and 4 were moved to classes 1 - 2 which reflects the high benefit of CABG in the study cohort. The NYHA classification represents a more complete clinical assessment of the patient's well-being [30], and Chow, *et al.* [31] reported that Postoperative NYHA class 3 - 4 was the only significant factor associated with 10-year all-cause mortality with an odds ratio of 6.3.

Strengths and Limitations

This study has strengths of dependence on electronic medical records that have a uniform classification of the procedures and clinical variables, with the distinction between co-morbidities and complications, and which reflect the current patient severity and surgical practice. Further, the study did not focus on a narrow patient population, and it included all patients who underwent isolated CABG operations, completed the follow-up period of at least 24 months, and with no missing data. This would widen the spectrum of generalization of the results after future validation of the developed risk stratification models. Moreover, the study addressed the long-term outcomes of CABG which are currently of more concern. On the other hand, the retrospective study design carries potential procedure and detection bias, and the results might have been affected by unmeasured confounding variables. Another limitation is that data were obtained from a single center, which might limit the generalizability of the results.

5. Conclusion

A risk prediction model was developed in a Saudi cohort for predicting all-cause mortality risk during both hospital admission and the follow-up period of at least 24 months after isolated CABG surgery. These risk prediction models help to get a complete prognosis and thus facilitate evidenced-based surgical decision-making. A set of models were also developed for predicting long-term risks of all-cause recurrent hospitalization, recurrent chest pain, heart failure, and the need for revascularization by using stents. The developed models are based on easily accessible preoperative, operative, and postoperative clinical factors. After future validation of these risk models, they can be used to identify vulnerable patients enabling the intensification of follow-up visits and the recommended treatment in these patients.

Author Contributions

Ayman R. Abdelrehim, Ibraheem H. Alharbi, Fatma A. Taha, Hasan I. Sandogji, Mohammad Nizam S. Uddin and Waheed Fouda contributed to conception, design of the study. Tousif K. Khan, Amir A. ElSaid, Fath A. Alabsi contributed to analysis and interpretation of data. Ayman R. Abdelrehim and Ahmed M. Shabaan wrote the initial draft of the article. All authors agreed to the final version of the manuscript to be published also they have agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Ethics Approval and Consent to Participate

The study was approved by the Research Ethics Committee of the General Directorate of Health Affairs in Madinah National Registration Number (ID: IRB23-047), confidentiality of the participants' data was ensured by keeping the data sheets anonymous after assigning a code number specific to each patient, which is known only by the investigators.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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