INTERACTIVE VOICE RESPONSE TECHNOLOGY AND SURGICAL MONITORING FOR CARDIAC PATIENTS IN PRE-HABILITATION AND POST-SURGERY: EVIDENCE OF IMPACTS ON PROCESS AND OUTCOMES OF CARE

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Abstract

Background: In cardiac surgery, poorer health-related quality of life (HRQOL) after surgery has been associated with worse survival outcomes. However, it is unclear how HRQOL is impacted by a combination of a cardiac surgical procedure and a patient health optimizing process prior to surgery known as *"prehabilitation"*. This study addresses this area by investigating changes in HRQOL among cardiac surgery patients undergoing prehabilitation.

Methods: Prehabilitation program patients (n=460) awaiting coronary artery bypass graft (CABG) surgery over a 31-month period were included in the study. All patients completed the 12-item short-form (SF-12; physical component scale, PCS-12; and mental component scale, MCS-12) health survey HRQOL questionnaire at 1-day post-program enrolment (pre-surgery) and at 3-months post-CABG surgery discharge via automated interactive voice response (IVR) system call. Patients were stratified by whether they raised a flag in the pre-surgery IVR call, indicating need for prehabilitation intervention.

Results: Before surgery, non-flagged patients (i.e., no intervention needed pre-surgery) (n=129) had a statistically significant higher median MCS-12 score than flagged patients (n=331); PCS-12 score difference pre-surgery was statistically insignificant. After discharge, median MCS-12 and PCS-12 scores increased for both groups. but only the PCS-12 score difference was statistically significant. However, no significant differences in ranked change scores for MCS-12 and PCS-12 were noted, indicating comparable effects post-surgery.

Conclusion: HRQOL for patients needing prehabilitation intervention improved and was comparable to non-flagged patients' HRQOL post-discharge. Since flagged patients had lower mental HRQOL than non-flagged patients' pre-surgery, IVR-enabled prehabilitation improved mental wellbeing by providing a feeling of security and involvement in their health.

Table of Contents

ABSTRACT II

LIST OF ABBREVIATIONS AND ACRONYMS V

LIST OF FIGURES VI

1 INTRODUCTION 1

1.1 BACKGROUND 1
1.2 STATEMENT OF PROBLEM/RATIONALE 3

2 LITERATURE REVIEW 6

2.1 CORONARY ARTERY BYPASS GRAFT 6
2.1.1 Overview of Coronary Artery Bypass Graft Surgery *6*
2.1.2 Relevance of Screening CABG Patients Prior to Surgery and Monitoring Post Surgery *11*
2.2 CORONARY ARTERY BYPASS GRAFT SURGERY PREHABILITATION PROCESS AT UOHI 14
2.3 INTERACTIVE VOICE RESPONSE SYSTEMS: INTRODUCTION AND USE IN PREHABILITATION 15
2.4 DIGITAL HEALTH TECHNOLOGY 16
2.4.1 Introduction and Overview of Digital Health Technology *16*
2.4.2 Digital Health Technology in Cardiac Care *17*
2.4.3 DHT and Other Technologies Used in Coronary Artery Bypass Graft Surgery Care *19*
2.5 RESEARCH QUESTIONS AND OBJECTIVES 21

3 CONCEPTUAL FRAMEWORK 22

3.1 FRAMEWORK FOR DEVELOPING AND EVALUATING COMPLEX INTERVENTIONS 22

4 METHODOLOGY AND MATERIALS 26

4.1 STUDY DESIGN 26
4.2 SETTING 26
4.3 RESEARCH PARTICIPANTS 27
4.4 DATA SOURCES AND MEASURES 27
4.5 ETHICS REVIEW AND APPROVAL 28
4.6 DATA ANALYSIS 29

5 RESULTS 30

5.1 DESCRIPTION OF STUDY POPULATION 30
5.2 DESCRIPTION OF OTHER PATIENT GROUPS 31
5.3 INTERACTIVE VOICE RESPONSE (IVR) SYSTEM TRENDS 35
5.3.1 IVR Trends Across All Timepoints for Study Population *35*
5.3.2 IVR Trends Across All Timepoints for Prehab Group *38*
5.3.3 IVR Trends Across All Timepoints for non-Prehab Group *40*
5.3.4 Differences in IVR Trends Between Prehab & non-Prehab Patients *40*
5.4 SHORT FORM 12 (SF-12) HEALTH SURVEY SCORES 41
5.4.1 SF-12 scores for all patients at all timepoints *41*
5.4.2 SF-12 scores for Prehab group patients *43*
5.4.3 SF-12 scores of flagged and not flagged Prehab group patients *45*
5.4.4 SF-12 for non-Prehab patients *50*
5.5 STUDY OUTCOME MEASURES (EXCLUDING SF-12) 51
5.5.1 Outcome Measures for Study Population *51*
5.6 REGRESSION ANALYSIS 52
5.6.1 Elucidating the most predictive factors for the study population *52*

5.6.2 Prehab Group Modelling *55*
5.6.3 Non-Prehab Group Modelling *62*

6 DISCUSSION **66**

6.1 IVR UTILIZATION TRENDS 66
6.2 EXAMINING VARIATIONS IN DEMOGRAPHIC CHARACTERISTICS ACROSS GROUPS 68
6.2.1 Comparison to prior research and across groups *68*
6.2.2 Comparing demographic characteristics across Prehab and non-Prehab patients *68*
6.2.3 Comparing demographic characteristics of flagged and not flagged patients *69*
6.3 DIFFERENCES IN STUDY OUTCOMES 70
6.3.1 Differences in post-operative outcomes between Prehab and non-Prehab patients *70*
6.3.2 Differences in post-operative outcomes between flagged and not flagged patients *71*
6.3.3 Differences in post-operative outcomes within flagged group split by flags raised *72*
6.3.4 Overview of SF-12 score trends for study population *72*
6.3.5 Overview of SF-12 core trends for Prehab patients *73*
6.3.6 Differences in SF-12 scores for flagged and not flagged Prehab patients *75*
6.3.7 SF-12 score differences between Prehab and non-Prehab patients after surgery *77*
6.3.8 Further exploring associations between potential predictor variables and study outcomes via regression analysis *78*
6.3.8.1 Associations between potential predictor variables and study outcomes for the study population 78
6.3.8.2 Associations between potential predictor variables and study outcomes for Prehab patients 79
6.3.8.3 Associations between potential predictor variables and SF-12 scores for Prehab patients 80
6.3.8.4 Associations between potential predictor variables and study outcomes for non-Prehab patients 81
6.3.8.5 Associations between potential predictor variables and study outcomes for flagged and not flagged patients 82
6.4 PREHAB AFU PROGRAM EVALUATION SUMMARY VIA FDECI FRAMEWORK 82
6.5 SYNTHESIS OF KEY FINDINGS IN RELATION TO STUDY OBJECTIVES 84

7 LIMITATIONS **88**

8 IMPLICATIONS **90**

9 FUTURE DIRECTIONS **91**

10 CONCLUSION **92**

REFERENCES **94**

APPENDIX **119**

List of Abbreviations and Acronyms

UOHI	The University of Ottawa Heart Institute
CABG	Coronary Artery Bypass Graft
CAD	Coronary Artery Disease
PCI	Percutaneous Coronary Intervention
IVR	Interactive Voice Response
AFU	Automated Follow-Up
SF-12	12-item Short Form Health Survey
PCS-12	Physical Component Scale
MCS-12	Mental Component Scale
MI	Myocardial Infarction
PLOS	Post-operative Length of Stay
ACS	Acute Coronary Syndrome
RIMA	Right Internal Mammary Artery
LIMA	Left Internal Mammary Artery
RCA	Right Coronary Artery
PDA	Posterior Descending Artery
LCA	Left Coronary Artery
LAD	Left Anterior Descending Artery
FFR	Fractional Flow Reserve
SVG	Saphenous Vein Graft
STS	Society of Thoracic Surgeons
EuroSCORE	European System for Cardiac Operative Risk Evaluation
ECG	Electrocardiograms
ECHO	Echocardiogram
BMI	Body Mass Index
CIHI	Canadian Institute for Health Information

FDECI	Framework for Developing and Evaluating Complex Interventions
BIC	Bayesian Information Criterion
VIF	Variance Inflation Factor
REB	Research Ethics Board
PROM	Predicted Risk of Mortality
STS PROM	Society of Thoracic Surgeons-Predicted Risk of Mortality
ICU	Intensive Care Unit
HRQOL	Health-Related Quality of Life

List of Figures

Figure 1. Visualization of typical Prehab AFU IVR algorithm. 4
Figure 2. Phases and core elements present within FDECI framework...................................... 25
Figure 3. Tree diagram of the groups/subsets of groups of patients within this study. 32
Figure 4. IVR trends for the study population between February 2021 and September 2023..... 36
Figure 5. SF-12 scores over time for three Prehab AFU patient groups.................................... 44
Figure 6. Median PCS-12 scores across two timepoints for flagged and not flagged patients.... 46
Figure 7. Median MCS-12 scores across two timepoints for flagged and not flagged patients. . 47

List of Tables

Table 1. Research perspectives within FDECI framework. 23
Table 2. Demographic Characteristics of the study population 30
Table 3. Demographic characteristics of Prehab and non-Prehab patients. 32
Table 4. IVR call responses for flagged and not flagged patients post-discharge 39
Table 5. IVR call responses for Prehab and non-Prehab patients post-discharge........................ 40
Table 6. SF-12 scores for all completed surveys across all timepoints...................................... 42
Table 7. SF-12 scores across two timepoints for flagged and not flagged patients. 45
Table 8. Comparison of SF-12 scores between flagged and not flagged patients at 6 months and 1-year post-discharge. 48
Table 9. Outcome Measures for study population, Prehab and non-Prehab group...................... 51
Table 10. Factors associated with PLOS for all patients via BIC backward elimination approach. 53
Table 11. Factors associated with readmission for all patients via BIC backward elimination approach. 54
Table 12. Factors associated with STS operative mortality for all patients via BIC backward elimination approach. 54

Table 13. Factors associated with PLOS for Prehab patients via BIC backward elimination approach. 56
Table 14. Factors associated with readmission for Prehab patients via BIC backward elimination approach. 56
Table 15. Factors associated with MCS-12 scores for Prehab patients at 3 months post-discharge via BIC backward elimination approach. 57
Table 16. Factors associated with PCS-12 scores for Prehab patients at 3 months post-discharge via BIC backward elimination approach 58
Table 17. Factors associated with MCS-12 scores for Prehab patients at 6 months post-discharge via BIC backward elimination approach. 59
Table 18. Factors associated with PCS-12 scores for Prehab patients at 6 months post-discharge via BIC backward elimination approach. 59
Table 19. Factors associated with MCS-12 scores for Prehab patients at 1-year post-discharge via BIC backward elimination approach. 60
Table 20. Factors associated with PCS-12 scores for Prehab patients at 1-year post-discharge via BIC backward elimination approach. 60
Table 21. Summary of MCS-12 predictive factors for Prehab patients at 3 timepoints. 61
Table 22. Summary of PCS-12 predictive factors for Prehab patients at 3 timepoints. 61
Table 23. Factors associated with PLOS for non-Prehab patients via BIC backward elimination approach. 62
Table 24. Factors associated with readmission for non-Prehab patients via BIC backward elimination approach. 63
Table 25. Factors associated with STS operative mortality for non-Prehab patients via BIC backward elimination approach. 63
Table 26. Post-operative length of stay predictive factors for three patient groups. 65
Table 27. Readmission predictive factors for three patient groups. 65
Table 28. STS operative mortality predictive factors for two patient groups. 66
Table 29. Relevant FDECI framework research questions and key takeaways.. 82
Table 30. Summary of research findings and conclusions. 85

1 Introduction

1.1 Background

Heart disease is the collective name for any medical condition that compromises either the structure or function of the heart (Heart and Stroke Foundation of Canada, n.d.-b). Heart disease, which affects approximately 2.4 million Canadians (Canadian Institute for Health Information, n.d.), is the 2nd leading cause of death in Canada; in 2020, heart disease was responsible for over 53,000 deaths or 17.5% of all deaths (Statistics Canada, 2022). There are several types of heart disease which are generally fall into one of the four following categories: Coronary artery and vascular disease, rhythm disorders, structural disease, and heart failure.

Coronary artery disease (CAD) is the most common form of heart disease in both the United States (CDC, 2021) and Canada (Heart and Stroke Foundation of Canada, n.d.-b). CAD occurs as a result of plaque building up within the walls of the arteries that supply the heart with blood (CDC, 2021). When this supply of blood is disrupted, any of three main types of medical conditions may occur. These are chest pain or discomfort (angina), heart attack (myocardial infarction), and sudden stopping of the heart beating (cardiac arrest) (Heart and Stroke Foundation of Canada, n.d.-a). These conditions can be life threatening. Myocardial infarction (MI) can progress into cardiac arrest; cardiac arrest can cause death within minutes if emergency first-aid treatment is not administered in a timely manner (American Heart Association, n.d.). If patients survive an MI or cardiac arrest, there is usually considerable damage that occurs which may result in life-long reduction in heart function (American Heart Association, n.d.). Therefore, it is vitally important to address CAD before it progresses to such a stage where these severe outcomes may occur.

There are three main treatment courses that are utilized to prevent CAD progression; these are medical therapy, percutaneous coronary intervention (PCI), and coronary artery bypass grafting (CABG) (Bachar & Manna, 2022). CABG is the standard of care, especially in further advanced CAD, due to improved survival outcomes in terms of mortality and quality of life when compared to PCI or medical therapy alone (Serruys et al., 2009). CABG is the most common major surgical procedure; just under 400,000 are completed worldwide on an annual basis (Bachar & Manna, 2022). In Canada, about 15,000 CABG procedures are conducted annually (Canadian Institute for Health Information, 2017).

Owing to the complex nature of the procedure, post-operation complications can occur. For instance, the overall 3-year risk-adjusted 30-day in hospital mortality after CABG for patients between 2018 and 2021 was 1.5 per 100 patients in Canada; this rate was at 1.4 per 100 for patients at UOHI (Canadian Institute for Health Information, 2022). Moreover, the Canadian average overall 3-year risk-adjusted 30-day all-cause readmission rate for CABG patients between 2018 and 2021 was 9.1 per 100 patients; this was 9.4 per 100 patients for CABG patients at UOHI in the same period (Canadian Institute for Health Information, 2022). In previous research, patients who were readmitted after CABG had a 5 times higher risk of in hospital mortality when compared to their peers who were not readmitted (Litwinowicz et al., 2015); this risk may be up to 10 times higher in some patients (Litmathe et al., 2009). Earlier discharge is also known to reduce costs to the healthcare system (as hospital care is more expensive than home care) and in some cases has been associated with lowering readmission risks (Williamson et al., 2022); this would then lower mortality risk as well.

The University of Ottawa Heart Institute (UOHI), which is the largest cardiac centre and leader in cardiovascular medicine in Canada, conducts several CABG procedures on an annual basis. For the period between 2021 and 2022, UOHI completed over 1,000 CABG procedures (University of Ottawa Heart Institute, 2022). The UOHI continues to seek ways to improve the standard of care for pre-, peri- and post-operative CABG surgery care; a new approach to pre-CABG surgery care is described in the following sections.

UOHI employs a rigorous standard of care for CABG patients. Currently, all patients waiting for CABG (i.e., non-emergency cases), heart valve replacement or repair surgery are enrolled into a prehabilitation program known as Cardiac Prehab (University of Ottawa Heart Institute, 2017). The Cardiac Prehab program standardizes the assessments and referrals that these waitlist patients might require before undergoing their cardiac surgery. These patients are called by a Prehab nurse to discuss a range of topics including medications, diabetes control, smoking, nutrition, physical activity, mental health and overall symptom management (University of Ottawa Heart Institute, 2017). As required, the Prehab nurse works with the patient to optimize medication, screen for diabetes, refer the patient to smoking cessation, as well as referrals to other healthcare professionals such as dietitians, social workers, psychologists (University of Ottawa Heart Institute, 2017).

The next phase of the process involves patients coming to UOHI for an in-person workshop. Along with their carers who will be assisting them after their surgery, patients learn several skills such as how to monitor their blood sugar or how to move safely after their procedure (University of Ottawa Heart Institute, 2017). Moreover, discussion surrounding logistical issues such as how the patient will be transported home post discharge or how to modify the home environment to make recovery at home more comfortable (University of Ottawa Heart Institute, 2017). As part of the constant drive from UOHI to improve patient care, the Prehab program underwent recent modifications that have streamlined the process for the Prehab providers and patients.

1.2 Statement of Problem/Rationale

To streamline this process the process of preparing patients for their CABG surgery journey at UOHI as well as optimizing patient health prior to surgery, the Prehab program expanded the use of interactive voice response (IVR) technology that prior to this change was utilized primarily in post-operative care for surgical patients at UOHI. This has allowed the Prehab program to automatically screen patients remotely for medical symptoms including increases in chest pain, chest pressure, shortness of breath, dizziness, or weakness. Moreover, patients can be screened to facilitate referral processes to healthcare providers such as social workers or specialized nurses that can assist patients with a range of issues including diabetes control, diet, post-discharge assistance, smoking cessation, or physical activity. Additionally, patients answer the 12-item short-form (SF-12) health survey that provides the Prehab program with further insight into the physical and mental health of the patient at the time of the survey. This program is now referred to as the Prehab Automated Follow-up (AFU) program.

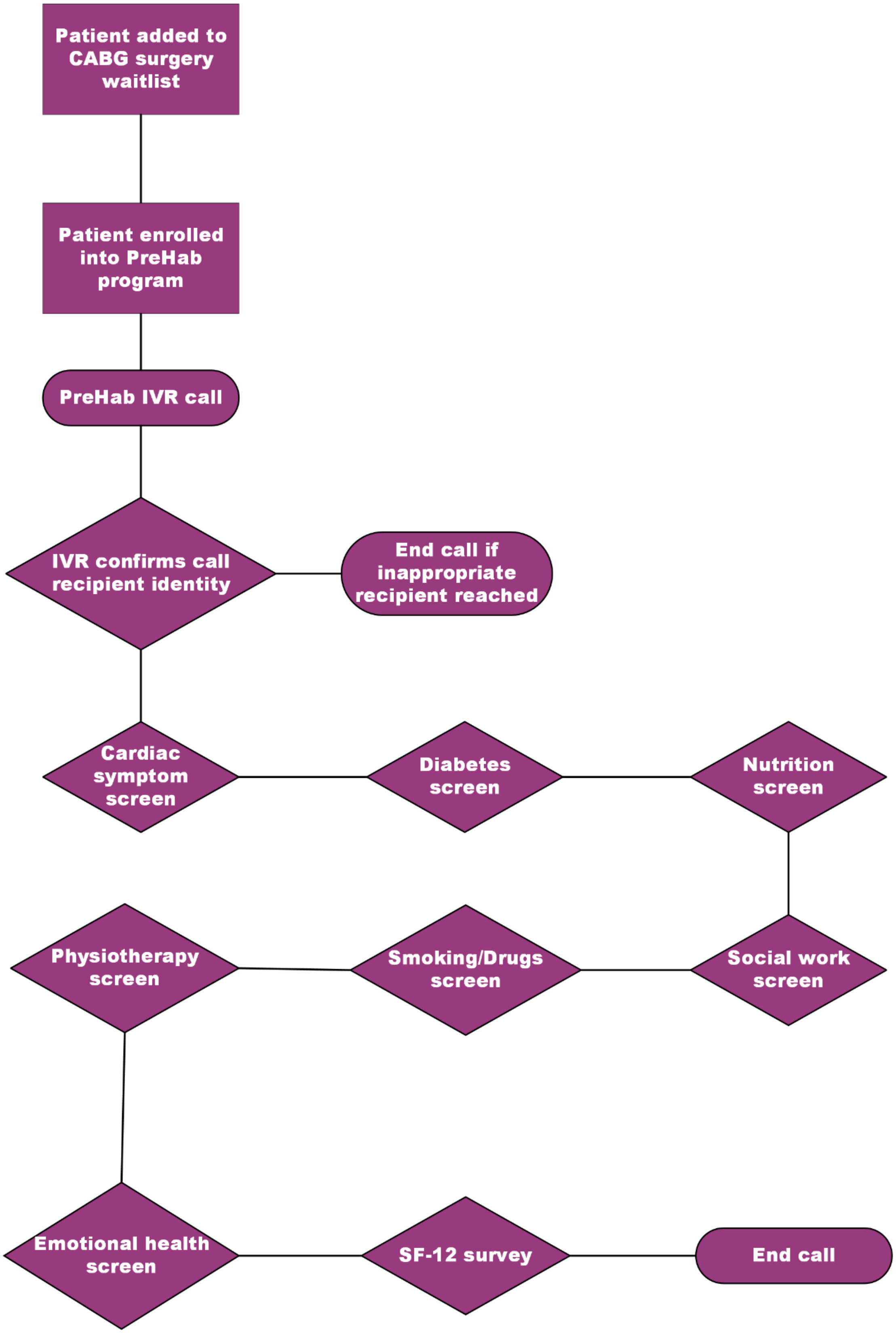

Figure 1. Visualization of typical Prehab AFU IVR algorithm.

An overview of the order of questions posed in the Prehab IVR algorithm (Figure 1) is described here. Firstly, the identity of the respondent to the automated call is established. Next, questions screening for medical symptoms (as described above) are asked and the patient is directed to appropriate next steps by the system if the answers indicate potential issues. If negative, the system proceeds with asking screening questions (as described earlier in the paragraph) that are then used by the team at UOHI to facilitate referrals to interventions or arrange callbacks if indicated; callbacks are calls that were completed by the patient via the IVR system but needed a nurse to call the patient back based on their responses to the IVR system queries. Finally, the SF-12 questions are asked, and patients respond by pressing the appropriate button on their telephone receiver to indicate their answers to the system. Upon completion of the SF-12 survey, the Prehab call thanks patients and terminates the conversation. By making use of IVR to remotely screen patients at the start of the Prehab AFU program, UOHI is seeking to assess the impacts that these modifications to the pre-operative care process have had on patients.

The Prehab AFU program at the UOHI represents an innovative approach for optimizing patients for surgery to improve their health condition pre-surgery and subsequently contribute to better outcomes and lower re-admissions. There is a current growing body of literature emphasizing the improvements to clinical outcomes for patients post cardiac surgery that prehabilitation can have (Rouleau et al., 2022). To date, limited research has assessed the impacts that prehabilitation can have on cardiac surgery patients. This is reflected in the lack of guidance regarding cardiac prehabilitation in current guidelines; importantly, cardiac rehabilitation is recommended for all cardiac surgery patients who undergo revascularization procedures (Lawton et al., 2022). Although prehabilitation has been associated with improved function, muscle strength, and quality of life after surgery for orthopedic patients (Punnoose et al., 2023), there is limited evidence of the benefits of prehabilitation in cardiac surgery patients (Akowuah et al., 2023). As such, further research is needed to consolidate the case for including prehabilitation in the patient journey prior to CABG surgery. Technological tools such as the IVR system described in the Prehab AFU program can assist clinicians with furthering this research by routinely collecting data from patients, as well as by lightening resource burdens via automating screening and referral processes within the prehabilitation period.

2 Literature Review

2.1 Coronary Artery Bypass Graft

2.1.1 Overview of Coronary Artery Bypass Graft Surgery

Coronary Artery Bypass Graft (CABG) surgery is a major surgery that is completed several thousands of times a year. The CABG procedure is a procedure whereby blocked arteries that provide blood to the heart, i.e., the coronary arteries, are bypassed by using a graft that allows blood to flow around the blockage(s). The condition that most commonly leads to a patient undergoing CABG surgery is Coronary Artery Disease (CAD) (Cleveland Clinic, 2022). CAD is characterized by blockages in the coronary arteries that supply oxygenated blood to the heart (Gopalan & Kirk, 2022). The blockages that cause CAD generally occur due to a process known as atherosclerosis; this is a process whereby arteries become clogged over time by a buildup of plaque (composed of cholesterol and other materials) (Gopalan & Kirk, 2022). The coronary arteries extend from the aorta and are divided into the right and left coronary arteries (Gopalan & Kirk, 2022). The right coronary artery (RCA) delivers blood to the right atrium, parts of the right and left ventricle, and the system responsible for conduction of the heart. The RCA branches off into the posterior descending artery (PDA) and 1 or more marginal arteries (Gopalan & Kirk, 2022). The left coronary artery (LCA) supplies blood to the left atrium and ventricle, as well as the interventricular septum; the LCA branches off into the Circumflex artery and the left anterior descending artery (LAD) (Gopalan & Kirk, 2022). A blockage in any of the arteries mentioned previously can lead to issues with blood flow to the muscular layer of the heart known as the myocardium (Tran et al., 2023). The myocardium is primarily responsible for the contractions that allow the heart to pump blood; when the myocardium is receiving lower blood flow which results in lesser nutrient and oxygen delivery, the myocardium is unable to effectively carry out its main function (Tran et al., 2023). This disruption to regular myocardial function results in angina, MI, and can ultimately lead to cardiac arrest (Heart and Stroke Foundation of Canada, n.d.-a). Therefore, there is an urgent need to prevent CAD from proceeding to this advanced stage whereby it can endanger life.

To get to the stage at which CABG is indicated for patients, the CAD in the patient must advance past a few disease stages. In the early stages of CAD, the focus on treatments is to that target the risk factors for developing CAD, especially those that are considered modifiable; these are risk factors that can be impacted by medical treatment. Non-modifiable risk factors include age, sex, ethnicity, and family history. A greater prevalence of CAD is noted in adults over the age of 35; the lifetime risk of an adult developing CAD after turning 40 years old is 49% in men and 32% in women (Sanchis-Gomar et al., 2016). Ethnicity too can impact a person's risk of developing CAD; American studies have indicated that individuals of Black (Carnethon et al., 2017), Latino (Rodriguez et al., 2014), or South Asian descent (Volgman et al., 2018) have higher risks of developing and dying from CAD. Family history can greatly impact the risk of developing CAD; having a male parent or sibling diagnosed with CAD before turning 55 years old or a female parent or sibling diagnosed before they turn 65 years old are established risk factors (Hajar, 2017). Although these non-modifiable risk factors are thought to be responsible for approximately 63% - 80% of the development and progression of CAD as seen in risk models, there is considerable benefit that can be realized from tackling the modifiable risk factors of CAD (Pencina et al., 2019). These risk factors include other medical conditions such as hypertension (also referred to as high blood pressure), hyperlipidemia (also known as high cholesterol), diabetes mellitus, and obesity; lifestyle related factors include smoking, poor diet, and sedentary lifestyle (Brown et al., 2023). In addition to these established risk factors, newer research has indicated that medical conditions including non-alcoholic fatty liver disease, chronic kidney disease, systemic lupus erythematosus, rheumatoid arthritis, inflammatory bowel disease, human immunodeficiency virus, thyroid disease, low testosterone, and vitamin D deficiency may become risk factors for CAD in the future if further research corroborates initial findings on the risk enhancing characteristics of these conditions with respect to CAD (Brown et al., 2023). As such, the current medical interventions aim to target these modifiable risk factors to either prevent the development of CAD or to slow down progression of the disease.

There are three main categories of intervention available: medical therapy, percutaneous coronary intervention (PCI), and coronary artery bypass graft (CABG) surgery. These three categories of treatment are usually considered after lifestyle modification alone is unsuccessful at alleviating symptoms for the patient. Lifestyle modifications aim at lowering the risk of further progress of CAD by directly addressing modifiable risk factors for CAD. Common changes involve changes to healthier diets (such as the plant-based Mediterranean diet), increasing physical activity levels, promoting weight loss, cutting out tobacco use, managing hypertension, and tighter control of diabetes (Regmi & Siccardi, 2023). If lifestyle modifications alone are unsuccessful in relieving symptoms, the next option available is medical therapy combined with lifestyle modifications.

Medical therapy for CAD patients involves taking a course of medications along with lifestyle modifications for varying lengths of time. There are six main categories of medications that are available for tackling CAD; antiplatelets, statins, beta-blockers, angiotensin-converting enzyme inhibitors (also known as angiotensin II receptor blockers), aldosterone antagonists, and calcium channel blockers (Reed et al., 2022). These medications aim to decrease the risk of blood clotting (Mehta et al., 2018), lower cholesterol for patients with CAD or at high risk of developing CAD (due to non-modifiable risk factors) (Pearson et al., 2021), relieve angina symptoms (Reed et al., 2022), lower blood pressure (Herman et al., 2023), regulate potassium and sodium levels to exert a diuretic effect (Smith et al., 2011), and assist blood pressure control for those with stable angina (Fihn et al., 2012) respectively. Thus, patients with CAD will usually be prescribed one or more of the described medical therapies alongside lifestyle modifications to prevent further progression of CAD. If this combination is unsuccessful, the next stage of addressing CAD involves surgical intervention (also referred to as revascularization).

The two revascularization options that are available to treat advanced CAD are PCI and CABG. PCI is the less invasive of the options; as such, PCI is utilized in cases whereby the patient has a surgical risk that is considered too risky for undergoing CABG (Lawton et al., 2022). This is, in large part, due to the less invasive nature of the PCI procedure. PCI aims to unclog coronary arteries and maintain the width of the opened coronary artery; this is usually achieved with a balloon and stent insertion. A catheter with an inflatable balloon that is overlayed by a stent is inserted either via a radial (wrist) or femoral (upper leg) artery and guided to the coronary artery in question (Ahmad et al., 2022). Once there, the balloon is inflated to deploy the stent, and the catheter is removed from the body. Most patients can be discharged approximately 6 hours after their PCI procedure, which takes about 30 to 90 minutes in duration in most cases (University of Ottawa Heart Institute, n.d.-a). Moreover, recent research regarding a newer method of conducting PCI, known as Fractional Flow Reserve (FFR)-guided PCI, has shown benefits for younger patients. In a trial that compared CABG to FFR-guided PCI, patients younger than 65 years old in the FFR-guided PCI group had faster increases in quality of life and were more likely to be working a year after their procedure when compared to their peers in the

CABG group (Fearon et al., 2022). Despite this, there are several drawbacks of PCI when directly compared to CABG which is partly why CABG is considered to be the ‘gold standard’ revascularization option for advanced CAD (Welt, 2022). In the next section, these differences are discussed after an introduction to the CABG revascularization procedure.

All CABG procedures are conducted with the aim of bypassing blockages in one or more coronary arteries (Bachar & Manna, 2022). However, there is a range of ways in which these blockages can be bypassed. When it comes to deciding which type of graft to be utilized, there are generally three candidates: the internal mammary/thoracic arteries, the saphenous vein, and the radial artery. However, recent American guidelines lean towards the internal mammary arteries, if viable, as the main choice of bypass conduit (Lawton et al., 2022).

The choice of which of the three grafts to utilize in a CABG procedure are guided by the clinical and technical factors that are present on an individual patient level. In general, the use of the LIMA to bypass the LAD has been evidenced in several large trials and is the first choice unless it is deemed not suitable for the patient (Lawton et al., 2022). The next option would involve either using the RIMA in place of the LIMA to bypass the LAD, or using the RIMA and LIMA together to graft the LAD (Lawton et al., 2022). If bypass of other coronary arteries (i.e., other than the LAD) is indicated, guidelines recommend using grafts harvested from the radial artery instead of SVGs (Lawton et al., 2022). Previous research indicates that patients that underwent CABG using SVG fared worse than those who underwent CABG with radial artery grafts when comparing incidence of MI and need for repeat revascularization (Gaudino et al., 2018); deaths were also lower in the latter group of patients (Gaudino et al., 2020). Furthermore, LIMA has proven to be superior to SVG as well; prior studies have established that patients who received LIMA grafts in CABG are associated with improved survival odds over a 15 year period post surgery when compared to patients who were treated with SVGs in CABG (Cameron et al., 1996). Therefore, surgical teams have several options available in terms of grafts that can be utilized in a CABG surgery. There is another key decision that surgical teams must make before conducting a CABG procedure; namely, whether to use or forego cardiopulmonary bypass.

Surgical teams must decide between whether to carry out the CABG procedure with cardiopulmonary bypass (on-pump) or without cardiopulmonary bypass (off-pump). Traditionally, CABG has been conducted on-pump which requires the use of cardiopulmonary bypass machine (sometimes referred to as the heart-lung machine) to continue circulating blood throughout the body while the heart is stopped (Shekar, 2006). Off-pump CABG is a newer approach to CABG and was developed, at least partially, due to some of the more concerning risks of on-pump CABG; this includes stroke and decreases in higher mental function (Shekar, 2006). However, prior research has been quite inconclusive in terms of which is the superior approach (Lawton et al., 2022). For instance, a recent trial found no statistically significant differences between off-pump and on-pump CABG in terms of deaths or revascularization within 10 years of undergoing CABG (Quin et al., 2022). Thus, guidelines recommend off-pump CABG in certain circumstances; patients with significant calcification of the aorta or those with advanced pulmonary disease are recommended to undergo off-pump CABG if conducted by experienced surgical teams (Lawton et al., 2022). There are also general risks of surgery that surgical teams must weigh when deciding the manner of CABG that they choose to proceed. These are generally determined using methods that aid teams in calculating risk scores for patients; these are outlined in the following section.

There are two main scoring systems that are utilized to predict the risk of having an adverse event occurring post CABG surgery; the Society of Thoracic Surgeons (STS) risk score and the European System for Cardiac Operative Risk Evaluation (EuroSCORE) II (Lawton et al., 2022). The STS risk score considers several types of individual factors, such as age or body mass index (BMI), as well as clinical factors, such as history of MI or recent cancer diagnosis, to provide surgical teams with information on the predicted risks of proceeding with CABG (O'Brien et al., 2018). The STS risk score provides predictions of 10 different outcomes that includes risk of mortality, stroke, and revascularization (O'Brien et al., 2018). The STS predicted risk of mortality (STS PROM) is categorized conventionally in the field into the following risk levels: low risk (less than 4% mortality risk), intermediate risk (4% to less than 8%), and high risk (8% and greater) (Kim et al., 2023; Kumar et al., 2018). The EuroSCORE II also provides similar information to the STS risk score and is easier to use owing to a reduced number of input variables when comparing to the STS risk score (Ad et al., 2016). However, the STS risk score performs better than the EuroSCORE II, especially when trying to predict the risk of mortality for populations at higher risk levels (Ad et al., 2016; Lawton et al., 2022).

By combining several pieces of information that relates to the choice of bypass graft conduit, the choice of going on-pump or off-pump, and the surgical risks associated with a patient undergoing CABG, surgical teams arrive at the best possible method to carry out CABG surgery for their patient. Thus, to enhance the surgical teams understanding of individualized risks, it is of considerable importance to screen patients prior to surgery.

2.1.2 Relevance of Screening CABG Patients Prior to Surgery and Monitoring Post Surgery

The number and different types of interventions that CABG patients enrolled in the Prehab AFU program is maintained by the UOHI. These interventions include the following: medication optimization, diabetes control, smoking cessation, nutrition, physical activity, mental health, and symptom management (University of Ottawa Heart Institute, 2017). Medication optimization could include changes to the patients' medication regimen. For instance, certain medications such as P2Y12 receptor inhibitors or short-acting glycoprotein inhibitors would need to be stopped a few days or a few hours respectively before CABG surgery to reduce the risk of major bleeding (Lawton et al., 2022). Other medications might need to be started, such as beta-blockers, to reduce the risk of adverse cardiovascular events such as arrhythmia or atrial fibrillation from occurring (Lawton et al., 2022). Diabetes control is incredibly important in patients about to undergo CABG. Patients with diabetes have a higher mortality rate and require revascularization more often than their non-diabetic peers after undergoing CABG surgery (Armstrong et al., 2013). Moreover, diabetes is a known risk factor for developing postoperative sternal wound infections (Arnaout & Goge, 2018); sternal wound infections significantly increase mortality risk for CABG patients (Gelijns et al., 2014). In a small study with 24 patients at UOHI, there were differences seen in those who attended Prehab diabetic control training and those who did not attend the intervention; one sternal wound infection was seen in the former group whereas three were seen in the latter group (Arnaout & Goge, 2018). Larger studies in the past have established the benefit of having a greater control over a patient's diabetes before CABG surgery; one such study demonstrated that tighter control was associated with lower incidence of atrial fibrillation, shorter post operative length of stay in hospital, a higher rate of survival at 2 years after surgery, and less recurrent wound infections (Lazar et al., 2004). As such, guidelines recommend the use of intravenous insulin during CABG surgery and in the early post operative phase to control blood glucose concentrations tightly (Lawton et al., 2022).

Smoking cessation is another important intervention that can contribute greatly to patient outcomes post CABG surgery.

Smoking affects outcomes post CABG surgery in several distinct manners. Smoking is an established risk factor for the development of surgical site infections; these infections greatly increase a patient's mortality risk, increase post operative length of stay, raises the likelihood of readmission, and chance of undergoing another revascularization procedure (Rogers et al., 2019). Smoking cessation of at least 4 weeks before undergoing CABG surgery has been established to be beneficial in terms of patient outcomes. For instance, this has been associated with reducing the risk of having post operative complications such as the patient requiring reintubation, undergoing a full tracheotomy, and acquiring lung infections (Benedetto et al., 2014). Moreover, there was some limited evidence (not statistically significant) that this timing of smoking cessation is associated with lowering the post operative length of stay (PLOS) as well as mortality risk while in hospital (Benedetto et al., 2014). The nutritional status of a patient also plays a role in the outcome that the patient faces after undergoing a CABG procedure.

Patients that undergo cardiac surgery and are underweight (having a BMI of less than 18.5) face a higher risk of mortality than their peers who are at normal BMI (between 18.5 and 25), overweight BMI (between 25 and 30), obese BMI class I (between 30 and 35), and obese BMI class II (between 35 and 40) (Mariscalco et al., 2017). This might relate to the concept of malnutrition, which is a common co-occurrence in someone who is underweight (McCann et al., 2019). Malnutrition is thought to be present in almost a fifth of patients that undergo cardiac surgery (Chermesh et al., 2014). These malnourished patients face higher risks of post operative mortality while in hospital, increased risk of infections, and having longer post operative length of stay than their well nourished counterparts (Chermesh et al., 2014). Unintentional weight loss before cardiac surgery too has been associated with a longer post operative length of stay (van Venrooij et al., 2008); this might be related to frailty and losing muscle mass which are associated with poor post operative outcomes (McCann et al., 2019). As such, nutritional supplementation might be considered for these patients with dietary changes, such as boosting calorie and protein intake, that aim to improve the nutritional status of the patient before undergoing cardiac surgery (Hill et al., 2022). Physical activity, an intervention that is linked with nutritional status, is another important intervention that aims to better post operative outcomes for CABG surgery patients.

Physical activity has been demonstrated to have several beneficial impacts on the outcomes for patients after cardiac surgery. Prehabilitation programs that include exercise programs have been associated with post surgery improvements in 6 minute-walking distance, reductions in post operative length of stay, and lower risk of atrial fibrillation in patients younger than 65 years old (Steinmetz et al., 2023); the 6-minute walking distance is a test that replicates the functional exercise level and effort that people typically utilize in their daily activities ("ATS Statement," 2002). This physical activity intervention can also include teaching the patient how to move safely post surgery (University of Ottawa Heart Institute, 2017); this can include avoiding certain activities or postures to avoid issues such as putting strain on the sternal wound or impacting circulation of blood (University of Ottawa Heart Institute, n.d.-c). Another important intervention relates to a different type of health; specifically, mental health.

Mental health is an emerging aspect of cardiac prehabilitation. CABG surgery is a life event that can be quite stressful for some patients; patients can experience anxiety, fear, and depression while waiting for their surgery (Feuchtinger et al., 2014). It has also been established that depression raises the mortality and morbidity risk for CABG surgery patients (Flaherty et al., 2017). Furthermore, in CABG patients who had scores associated with depressive symptoms based on a symptom checklist, these scores predicted greater length of post operative stay as well as having post operative complications such as arrythmia and angina ("Depression Predicts Perioperative Outcomes Following Coronary Artery Bypass Graft Surgery," 2010). As such, there has been a recent growing body of research that has examined the possibility of psychologically preparing patients before undergoing cardiac surgery. This form of preparation can include techniques that aim to improve aspects such as perceived social support and expectations, as well as reducing anxiety and depressive symptoms (Salzmann et al., 2020). There has been some, albeit limited, evidence that preparation in the form of pre-operative education, psychosocial support, and managing beliefs and expectations for patients has been linked to better post operative outcomes before undergoing cardiac surgery (Salzmann et al., 2020). Another related intervention to mental health involves symptom management. This can include managing stress management that involves the use of relaxation techniques; there is some evidence that cardiac surgery patients who receive stress management training during cardiac rehabilitation have lower rates of adverse post operative outcomes (Blumenthal et al., 2016). Therefore, there is a need to screen patients for these issues prior to undergoing CABG surgery as it is expected to improve outcomes post-surgery. This screening process is described in the overall surgical journey for CABG patients at UOHI in the following sections.

2.2 Coronary Artery Bypass Graft Surgery Prehabilitation Process at UOHI

Once waitlisted for CABG surgery at UOHI, all eligible patients are referred to the Prehab AFU program. This is a program that expands upon the concept of a form of rehabilitation known as cardiac prehabilitation. Prehabilitation, also referred to as pre-operative rehabilitation, can be defined as a process whereby patients undertake activities typically related to rehabilitation (i.e., physical therapy, respiratory therapy) before undergoing surgery. Prehabilitation programs generally aim to make patients more resilient to the stressors associated with undergoing major surgery by reducing the impact that the patient's risk factors can have on their post-operative outcomes (McCann et al., 2019). Cardiac prehabilitation is thought to have developed after prior research consolidated the importance of cardiac rehabilitation; cardiac rehabilitation has been shown to reduce cardiovascular mortality (deaths due to heart conditions), increase quality of life, and decrease readmissions to hospital (Anderson et al., 2016). Cardiac prehabilitation extends this concept of cardiac rehabilitation by including screening for existing medical conditions that could cause undesirable post-operative outcomes (Knight et al., 2022). Some research indicates that cardiac prehabilitation may provide benefits to patients by increasing the rate at which patients enroll in and complete cardiac rehabilitation (Rouleau et al., 2022); this will then provide benefits via cardiac rehabilitation that are well established in the field (Lawton et al., 2022). Other research has indicated that cardiac prehabilitation may have an effect on reducing PLOS for patients but the lack of trials renders this evidence as moderate (Yau et al., 2021).

In addition to the lack of evidence to support cardiac prehabilitation for cardiac surgery patients, there is also a limited amount of information on monitoring of cardiac surgery patients before their surgery or while undergoing prehabilitation as well. Thus, trials in progress such as the Digital Cardiac Counseling trial which is currently recruiting patients are aiming to examine the effect of personalized prehabilitation with digital monitoring on post cardiac surgery outcomes (Scheenstra et al., 2021). To do so, researchers can leverage several distinct types of technologies to assist them with furthering research into the effectiveness of prehabilitation. One such technology that is currently being utilized by the Prehab AFU program is known as Interactive Voice Response (IVR) Systems. This technology is further detailed in the following section, as well as its role within the Prehab AFU program. Along similar lines, the Prehab program at UOHI has recently introduced a novel approach to carrying out this screening process of cardiac prehabilitation by utilizing a technology known as Interactive Voice Response (IVR) systems.

2.3 Interactive Voice Response Systems: Introduction and Use in Prehabilitation

IVR systems have been utilized in various capacities in healthcare for almost three decades; an early example of IVR within healthcare was used in a tobacco cessation support helpline (Burke, 1993). IVR systems can be defined as computer based automated telephone systems that utilize telephone hardware and involve the manipulation of a voice digitally (Lee et al., 2003). Essentially, an IVR system call can be thought of as an interview where the interviewee (i.e., the patient) answers the questions being posed by the interviewer (i.e., the automated IVR system) by tapping buttons on a telephone (Corkrey & Parkinson, 2002). At UOHI, IVR has led to better compliance to medication in cardiac surgery patients post surgery (Sherrard et al., 2009), higher compliance to medication and lesser adverse events in Acute Coronary Syndrome (ACS) patients (Sherrard et al., 2015), and increases in medication compliance and lower hospital readmissions for heart failure patients (Ben Ismail et al., 2022). Therefore, this iteration of using IVR by the Prehab AFU program seeks similar improvement in outcomes for patients after CABG. The process of using IVR in the Prehab AFU program is described in the following section.

The IVR system in the Prehab AFU program allows the clinical team to screen patients during the prehabilitation phase by automatically triggering follow up calls with a nurse if patients respond negatively to questions posed via a unique algorithm. Moreover, patients are asked to complete a health survey via the IVR system as well. The survey, known as the Short Form 12-item health survey (SF-12), asks physical and mental health questions. The SF-12 is a shorter form of the SF-36; the SF-36 is a health survey that asks patients 36 questions that aim to assess health-related quality of life (HRQOL) of the respondent (Lins & Carvalho, 2016). The SF-12 has been established to be a suitable alternative to the SF-36 (Ware et al., 1996).

Moreover, in patients with coronary heart disease including CABG patients, the SF-12 has been demonstrated to be a reliable method of measuring HRQOL (Müller-Nordhorn et al., 2004). The SF-12 has also been studied in terms of its predictive value in cardiac patients; a recent study demonstrated that lower scores on the SF-12 (i.e., worse self-reported rating of physical and mental health) was associated with higher rates of readmission and mortality in the first year after discharge from hospital with a cardiac disease diagnosis (Christensen et al., 2020). As such, the collection of SF-12 data in combination with the screening questions can provide the surgical team with important information on aspects surrounding CABG surgery. The use of IVR is not restricted to the prehabilitation phase, CABG patients at the UOHI continue to receive IVR calls throughout the recovery process once discharged home for up to one-year post-discharge. In the recovery phase, IVR continues to act as an important safety net for patients by continuing to screen patients for cardiac related symptoms and triggers alerts for the clinical team in a similar manner to the prehabilitation phase. As such, the Prehab AFU program leverages IVR technology at several distinct timepoints throughout the typical patient journey for CABG patients. However, apart from the use of IVR technology in CABG, there are several other digital health technologies or health information technologies that are utilized in cardiac care; these are discussed in the following section.

2.4 Digital Health Technology

2.4.1 Introduction and Overview of Digital Health Technology

Digital Health Technology (DHT) is a broad term that encompasses a broad range of technologies that could be categorized as software applications, mobile health, health information technology (such as electronic health records), telemedicine, telehealth, and wearable devices such as smartwatches (Center for Devices and Radiological Health, 2020; Health Canada, 2018). These types of technology provide several important benefits for healthcare providers and patients; benefits include reducing inefficiencies (especially administratively), increasing access to health information and services, reducing service gaps in remote communities, and reducing costs to name a few (Health Canada, 2018). DHT is most often utilized in areas of healthcare delivery such as disease management, diagnostics, and clinical decision support/making (Sharma et al., 2018). Moreover, healthcare research too benefits from using DHT in improving recruitment rates, bolstering research fundraising, and simplifying the various processes of providing informed consent (Sharma et al., 2018). Thus, there are a seemingly endless potential applications of DHT within modern healthcare.

2.4.2 Digital Health Technology in Cardiac Care

Similarly, DHT is utilized in several unique ways in modern cardiac care. The main functions of DHT in this field include remote monitoring, cardiac therapy, telemedicine, and remote screening.

Remote monitoring in cardiac patients can take several distinct forms. Remote monitoring allows physicians to monitor patients while they are at home. For example, the Telehome Monitoring program at UOHI enables physicians to track the weight and vital signs of heart failure patients for a few months post discharge (University of Ottawa Heart Institute, 2015). Once a day, patients weigh themselves and check their blood pressure; this information is automatically sent to staff at UOHI via a wireless tablet (University of Ottawa Heart Institute, 2015). Other technologies may also be used to remotely monitor cardiac patients, such as continuous pulse oximeters for blood oxygen levels or respiratory sensors for respiratory rate measurement (McGillion et al., 2018). Some of these technologies can automatically provide information to their healthcare providers without the need for patients to physically conduct a measurement. For instance, devices such as the implanted CardioMEMS device can remotely transmit pulmonary artery pressure to healthcare providers. Patients lie on a special pillow and start a measurement through a monitor in a process that is painless and does not produce any sensation; research findings have described how using the device has led to lower hospital readmission rates for heart failure patients (Abraham et al., 2016). Another more recent example includes wearable technology such as smartwatches. For example, the Apple Watch, a consumer device, has shown some promise in monitoring patients for irregular heart rhythms such as atrial fibrillation (Perez et al., 2019).

There are also several devices that can assist with physically altering or maintaining cardiac function in patients. For instance, individuals with severe heart failure may sometimes be fitted with a left ventricular assist device (LVAD); a recent example of the technology is the HeartMate 3 LVAD (Vaidya et al., 2023). This device is used to bolster ability of the left ventricle in the heart to pump blood to the body and overcome symptoms of advanced heart failure (Abbott, 2023); research has shown that the device is safe for use up to 2 years without replacement and associated with a low risk of stroke formation (Mehra et al., 2019). Other technology such as implantable cardioverter defibrillators enable completely automatic monitoring and correction of abnormally slow or fast heart rates and abnormal heart rhythms by administering shocks or sending electrical pulses to the hear (Healthwise Staff, 2022).

The process of delivering cardiac care in a telemedicine format has evolved rapidly alongside advancements in technology. In the past, telemedicine was delivered with basic technology in comparison to the options available today. For example, telemedicine at UOHI was delivered via video feed in the late 1990's (Cheung et al., 1998). Physicians physically located at UOHI were able to provide consultations to patients that were sitting in a telehealth dedicated room with a nurse; the nurse assisted by applying an electronic stethoscope, performing other physical examinations, and presenting diagnostic results from electrocardiograms (ECGs) or echocardiograms (ECHOs) (Cheung et al., 1998). These were transmitted in real time to the physicians via audio and video feeds which were found to be reliable in allowing physicians at UOHI to provide consultations to remotely located patients (Cheung et al., 1998). Currently, telemedicine consultations at UOHI are delivered to patients via the Ontario Telemedicine Network. Patients meet physicians at UOHI virtually from an examination room in a local hospital or community health centre where a nurse can utilize a digital stethoscope, an examination camera and perform physical examinations as directed by the consulting physician (University of Ottawa Heart Institute, n.d.-d). Other possible methods of video consultation available to providers of cardiac care include videoconferencing software such as Zoom or Microsoft Teams (Lam et al., 2021). Some institutions are also able to lend devices to patients for use during telemedicine consultations; for instance, portable ECGs or ECHOs can be used at home to provide physicians with real-time information on cardiac activity during a telemedicine consultation (Stanford Medicine Children's Health, n.d.).

Remote screening can take various forms; a common method of screening is to utilize IVR systems. One of the earliest uses of IVR in cardiac care was over 30 years ago in a pilot study where three patients with cardiomyopathy were monitored at home for 8 to 10 weeks. Their weight was monitored (patients kept a weigh scale next to the phone and relayed this information to the system) and questions surrounding potential cardiac symptoms such as swelling or dizziness were asked over the IVR system and responded to in a binary fashion (i.e., yes or no by tapping 1 or 0 on the phone receiver respectively) (Patel & Babbs, 1992). At UOHI, IVR is used to screen patients for a variety of potential conditions before they undergo cardiac procedures (Figure 1). Moreover, IVR at UOHI aids in screening of patients post-discharge when they are recovering from cardiac procedures, ACS, MI or have been deemed at high risk of readmission owing to advancing heart failure (University of Ottawa Heart Institute, n.d.-d). In the future, screening within cardiac care might utilize commercially available artificial intelligence IVR systems such as the Amazon Alexa which recent research has indicated to be promising (Ganni et al., 2023).

2.4.3 DHT and Other Technologies Used in Coronary Artery Bypass Graft Surgery Care

As part of the evolution of CABG surgery care, the utilization of various pieces of DHT and other technologies has grown in recent years. The pre-operative process for CABG patients has changed in recent years. For example, some cardiac care centres are utilizing technology to remotely deliver prehabilitation programs for CABG patients before they undergo their procedure. This can include the use of a virtual platform along with devices such as heart rate monitors (Scheenstra et al., 2021).

The technology that the surgical team typically employs during the CABG procedure has evolved greatly. Graft harvesting techniques such as endoscopic vein harvesting (Mahmoud & Widrich, 2023) utilize advances in surgical tools and cameras to enable the harvesting of SVG with minimal incisions to the leg that lowers the risk of infections and further complications at the harvest site (Kopjar & Dashwood, 2022). The heart lung machine that is used when the patient undergoes on-pump CABG too has improved over time. Early machines weighed over 2000 pounds and had a limited ability to oxygenate blood (Stoney, 2009). The latest machines, such as the latest system from LivaNova, have automatic sensors to conduct system checks before starting cardiopulmonary bypass, have digital screens for easy monitoring and data entry, and can electronically share live data into hospital electronic medical records (Dolci, 2023). Surgical techniques have also improved with the rapid advancements in technology. For instance, minimally invasive techniques such as totally endoscopic coronary artery bypass (Balkhy, 2021) or µCAB (Živković et al., 2023) rely on improvements in surgical robotic technology and endoscopic cameras to allow surgeons to complete CABG procedures with smaller incisions while avoiding sternotomy; smaller incisions are thought to reduce the risks of post operation complications such as sternal infections and reduce duration of hospital stay (Živković et al., 2023).

In the post CABG recovery phase, there are several different types of technology that have been utilized to aid patient recovery. For instance, remote monitoring of patients after discharge from hospital through automated calling such as the IVR system that is utilized by UOHI make use of technological advances to remotely screen patients for post-operation complications (University of Ottawa Heart Institute, n.d.-d). Other remote monitoring approaches may make use of mobile health smartphone applications in conjunction with monitoring devices such as blood pressure, oxygen saturation, heart rate, body temperature, ECG and blood glucose (Atilgan et al., 2021) to closely monitor patients after cardiac surgery; other technologies such as smartwatches and chatbot applications have also been used along with smartphone applications to facilitate transmission of images of sternal wounds (Londral et al., 2022). There are also some unique approaches to post CABG recovery while the patient is recovering in the hospital; wearable continuous vital signs monitors can offer healthcare teams with a non-invasive manner to monitor patients without requiring the current gold standard of an invasive arterial catheter (McGillion et al., 2022). Advancements in technology has also allowed cardiac rehabilitation for recovering cardiac surgery patients to be delivered virtually. For instance, some programs offer patients the opportunity to interact virtually with healthcare providers and other rehabilitation enrollees through a virtual world (Content et al., 2022). Other programs make use of a combination of monitoring devices such as smartwatches and mobile health applications to provide healthcare providers with data while patients carry out rehabilitative exercises at home (Nabutovsky et al., 2022). Importantly, remote cardiac rehabilitation has been noted to be a potential method for expanding access to cardiac rehabilitation (which is traditionally conducted in person) to those in rural areas (Champion et al., 2022); cardiac rehabilitation continues to be underutilized (Johnson et al., 2022) despite recommendations that all patients who have undergone revascularization procedures to complete a cardiac rehabilitation program (Lawton et al., 2022).

In summation, there are several knowledge gaps within the fields discussed above. In prehabilitation, it is still unclear if prehabilitation can improve post-operative outcomes as the limited research conducted to date has elucidated mixed results. In terms of the combination of prehabilitation and IVR technology, there remains some aspects that remain to be clarified. These includes a lack of knowledge as to whether the combination is impacting patients in a positive manner, and whether all patients are receiving equal benefits from the system. As patients can respond differently to and express differing opinions to the use of technology within healthcare, and specifically in rehabilitation (Wentink et al., 2018), there remains questions surrounding IVR and other technology use within prehabilitation. Therefore, the literature review indicates that there is a pertinent need to address several issues regarding cardiac prehabilitation; the issues that are addressed in this study are highlighted in the following section.

2.5 Research Questions and Objectives

This project addresses these gaps and investigates the following research questions:

- *Are there differences in IVR system utilization across distinct subgroups of CABG patients?*
- *Are there changes and differences in CABG patients' process of care and outcomes associated with the IVR technology use in the Prehab AFU program?*
- *Are there differences in outcomes of care among CABG patients when comparing across distinct subgroups or between CABG patients who require intervention post-IVR screening as opposed to their counterparts?*

To address these questions, this research will evaluate the impacts of IVR technology on the process of care and patients' health outcomes as well as self-rated health-related quality of life (HRQOL). Specifically, it focuses on the following objectives:

1. Evaluating the impacts of the IVR technology in the Prehab AFU program on the process of care for CABG patients by analyzing the pattern of utilization of Prehab interventions over time and the adjustments made in the process in preparation for the surgery (e.g., amount of calls completed, amount of calls with a callback requiring a nurse to assess patients further; the number of calls made at an individual patient level to facilitate referral to the appropriate Prehab intervention etc.).
2. Assessing the changes in patients' health status/HRQOL (SF-12) pre and post surgery and examining the association between the SF-12 score changes and the number of calls received by patients. It is hypothesized that if all other variables are controlled for, then

patients who receive a greater number of calls (i.e., callbacks from the IVR team indicating issues relating to cardiac symptoms, diabetes, nutrition and other shown in Figure 1) would have a higher probability of worse post-operative outcomes in comparison to their counterparts not facing these issues.

3. Assessing differences in CABG patients' outcomes between different subgroups of patients by differences, if any, in study outcome measures (i.e., readmission, STS operative mortality, PLOS, and SF-12 where appropriate). Regression analysis allows further examination of these differences between groups with statistical control for differences in risk factors, demographic characteristics, surgical differences, Prehab attendance and so on. It is hypothesized that patients having riskier/less healthier pre-surgery profiles are more likely to fare worse in terms of post-operative outcomes including having lower SF-12 scores post-surgery than their less risky peers. Also, by using regression analysis to determine what factors are significantly associated with SF-12 scores post-surgery, more insight can be gained towards understanding if different groups score differently when controlling for other possibly confounding variables.
4. Examine the differences in outcomes between CABG patients who require interventions after screening stage of IVR Prehab when comparing to their counterparts who do not require interventions post-screening, as well as comparing between patients by number of Prehab interventions signaled by responses to the IVR system. This will allow for further inferences to be drawn regarding the effectiveness of the Prehab AFU program. For instance, if the outcomes in the intervention requiring group improved by a larger percentage or decreased by a lower percentage than the group that requires no intervention, then this can be further evidence for the usefulness of cardiac prehabilitation before surgery in complex patients that have modifiable risk factors. Moreover, this will provide further information to what extent the amount or types of interventions can have on post surgery outcomes; this can aid in improving the generation of risk profiles for future CABG patients.

3 Conceptual Framework

3.1 Framework for Developing and Evaluating Complex Interventions

The Framework for Developing and Evaluating Complex Interventions (FDECI) is a widely utilized framework that has been utilized in areas such as healthcare services, social services, and public health (Skivington et al., 2021). This framework was originally developed by the Medical Research Council in the United Kingdom and the original version was published in 2000 before updates were made in 2006 and in 2019 (Skivington et al., 2021). In this study, the FDECI is utilized as a larger scale framework that aids in guiding the planned analysis of the use of IVR in the Prehab AFU program. In the following sections, the FDECI is explained in more detail and the relevant aspects of the framework that will guide this study are selected.

The FDECI is comprised of four research perspective domains that can be utilized to structure the conduct of complex intervention research: efficacy, effectiveness, theory based, and systems (Skivington et al., 2021). Efficacy is a term that describes whether an intervention produces desired outcomes in an experimental context (Skivington et al., 2021). Effectiveness is similar to efficacy but is focused on the impacts an intervention has in the context of real world application (Skivington et al., 2021). The theory based domain aims to understand how the complex intervention works on a theoretical level (Skivington et al., 2021). The systems domain analyzes the intervention as if it were acting as a disruptor to a larger more complex system that surrounds it (Skivington et al., 2021). These domains are described in more detail in the below table.

Table 1. Research perspectives within FDECI framework. Red underlined text indicates pertinent perspectives to the present study. Adapted from (Skivington et al., 2021).

Research Perspective/Question	**Main Considerations**
Efficacy	
To what degree does the intervention produce desired outcomes in ideal scenarios?	Simulated in theoretical/experimental settings within perfect environment. By maximizing internal validity, a precise and unbiased estimate of efficacy can be elucidated.
Effectiveness	
To what degree does the intervention produce desired outcomes in non-experimental/clinical settings?	Most commonly, compare intervention to usual treatment. Results will dictate decision

	between established treatment or new approach to achieve desired outcomes.
Theory Based	
What (about the intervention) functions in which conditions and how does it do so?	Goal is to better understand how change occurs, as well as the interactions between various mechanisms and context; can lead to theory refinement.
Systems	
How does the system in which the interventions functions in adapt to it and vice versa?	The intervention is seen as a disruptor to an existing complex system.

For this study, the domains of effectiveness and theory based will be utilized owing to the scope of the intended research. Specifically, the effectiveness domain will guide the analysis of the use of IVR in the Prehab AFU program as it is currently being used in a real-world clinical setting with real world impacts already being seen on CABG patients at UOHI. The theory domain will guide a discussion into the theoretical aspects of how the intervention is producing the desired outcomes in the target population.

The FDECI also provides further insight into the core elements that are present when conducting complex intervention research; these include *consideration of context, developing as well as refining and testing programme theory, engagement of stakeholders, identification of main uncertainties, refining the intervention, and economic considerations* (Skivington et al., 2021). Context is understood to be the location or setting in which the intervention is being implemented. Programme theory involves describing how an intervention is expected to perform within a given context. Stakeholders for the intervention include individuals who are the target of the intervention, deliver the intervention or have a stake in the intervention otherwise (Skivington et al., 2021). Key uncertainties are defined as the gaps in knowledge between what is already known and what the team carrying out the research or other stakeholders consider is vital to determine. Refinement of the intervention can occur at any time within the research and is generally based on feedback from stakeholders in the intervention. Economic considerations are considered via an evaluation of the benefits and costs of the intervention (Skivington et al., 2021). These core elements are considered during a four stage process for developing and evaluating complex interventions: these phases are development or identification of the intervention, feasibility, evaluation, and implementation (Skivington et al., 2021). Development or identification of the intervention has been considered prior to the initiation of the planned research; namely, an evaluation of the impacts of IVR use in the Prehab AFU program. As this intervention has already been implemented at UOHI and has been designed to fit the needs of clinical staff, the research can be considered as taking place during the evaluation phase of the process. Moreover, a keen focus on the main uncertainties of the intervention will be maintained that keeps in mind the impacts of the intervention for patients who are stakeholders (i.e., CABG patients at UOHI) in clinically important aspects that have been determined by the research team. A summary of these phases is displayed in the below figure.

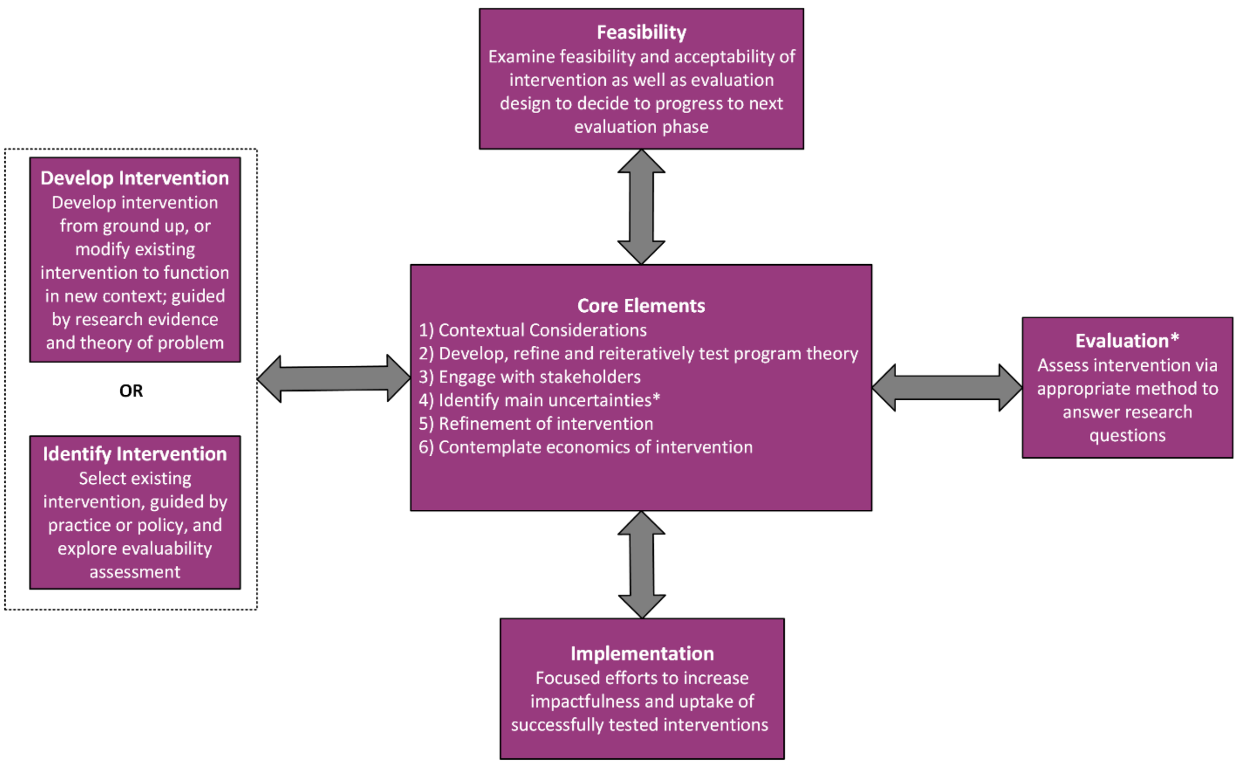

Figure 2. Phases and core elements present within FDECI framework. Asterisk indicates pertinent core element/phase of research to the present study. Adapted from (Skivington et al., 2021).

4 Methodology and Materials

4.1 Study Design

The present study is a pre-post assessment with a cross-sectional analysis of secondary data accessed at one timepoint to assess the impacts of IVR utilization in the Prehab AFU program on the process of care for CABG surgery patients as well as pre-operative and post operative outcomes. The research questions, which will be answered via statistical analysis that is discussed in future sections, focus on uncertainties regarding the impacts of the use of IVR in the Prehab AFU program intervention for patients such as determining if there are changes to patient outcomes for CABG patients after the incorporation of IVR in the Prehab AFU program, determining if any differences are seen between patients who require interventions during the Prehab AFU program and those that did not, and if outcomes for CABG patients have changed after IVR was added to the Prehab AFU program when comparing across distinct subgroups. Moreover, differences, if any, in self-rated health (via SF-12) between distinct subgroups of patients will be analysed to better understand how different subgroups of patients interpret the impacts of the Prehab AFU program on their HRQOL.

4.2 Setting

The University of Ottawa Heart Institute (UOHI), located in Ottawa, Ontario is the largest cardiac care centre in Canada (University of Ottawa Heart Institute, n.d.-e). Since the establishment of UOHI in 1976, the institute continues to grow in its role as a leader in cardiovascular medicine and now cares for over 210,000 patients annually (University of Ottawa Heart Institute, n.d.-b). On an annual basis, roughly 1,900 cardiac procedures are performed at UOHI by a dozen surgeons supported by over 1,400 staff members including other physicians, nurses, and other healthcare professionals (*Cardiac Surgery | University of Ottawa Heart Institute*, 2015; *Find a Specialist | University of Ottawa Heart Institute*, 2024). Furthermore, UOHI runs the largest cardiac prevention and rehabilitation in Canada through the Division of Cardiac Prevention and Rehabilitation which includes the Cardiac Rehabilitation team that delivers the Prehab AFU program.

4.3 Research Participants

All patients who completed a CABG procedure at the UOHI within the period between February 2021 and September 2023 were included in the study cohort; February 2021 was chosen as the start timepoint of inclusion for the cohort as this corresponds with the initiation of the Prehab AFU program.

Therefore, the data source for the intended research is patient data that is maintained by UOHI in a secure manner. To ensure that this confidentiality was maintained, there were safeguards in place to protect patient anonymity. Firstly, the author accessed a database file containing patient data that is deidentified and thus fully anonymized; no identifiable data was provided to the author of the present study, and the author did not attempt to access any identifiable data. Secondly, the author abided by and acknowledged confidentiality agreements that explicitly state the responsibilities of the author in terms of handling the data. This included not sharing information about the research study to individuals who have not acknowledged these confidentiality agreements and are outside of the scope of the study and deleting or returning all information used in the study from personal computing devices at the completion of the study. Lastly, when utilizing patient data to conduct statistical analysis, the researcher stored data in a secure computer that is protected by a password shared with no other individual. Moreover, the author took measures to ensure this secure computer was not in view of others such as only working in physical areas whereby no members outside of the scope of the study are present and did not leave this computer unattended in public areas.

4.4 Data Sources and Measures

To ensure the quality of data utilized in this study, the following steps were taken. Firstly, the dataset which holds the patient data was cleaned. This included the identification of missing data, if any, for the desired outcome variables as well as any measures that may not have been completed entirely (Rademaker & Polush, 2022). Then, missing data was removed if it did not compromise other facets of the study such as the sample size; a maximum missing data proportion of 5% was deemed to be acceptable keeping in accordance with previously established norms with respect to complete case analysis (Jakobsen et al., 2017).

All data utilized in the study originated from UOHI. As such, all data is stored on site and a secure environment for use by select healthcare professionals only. The author was provided with deidentified data originating from the Prehab AFU program team. To ensure the quality of data utilized in this study, the following steps were taken. Firstly, the dataset which holds the patient data was cleaned. This included the identification of missing data, if any, for the desired outcome variables as well as any measures that may not have been completed entirely (Rademaker & Polush, 2022). Then, missing data was removed if it did not compromise other facets of the study such as the sample size; a maximum missing data proportion of 5% was deemed to be acceptable keeping in accordance with previously established norms with respect to complete case analysis (Jakobsen et al., 2017).

The measures in the study are as follows: SF-12 survey scores, PLOS, readmission, and STS operative mortality. SF-12 scores can take on any value between 0 and 100 and are scored on a standardized basis. PLOS is measured in days, with any value possible above zero. PLOS was categorized as being long if greater than 14 consecutive days, medium if greater than 6 days but shorter than 14 days, and short PLOS was defined as being less than 6 days as per norms in the field (O'Brien et al., 2018). Readmission and STS operative mortality are binary categorical variables that yield a yes or no; these were coded as 0 and 1 for the purposes of regression analysis.

4.5 Ethics review and Approval

Ethical approval for the intended research was sought from the Research Ethics Board (REB) at UOHI in November 2023. The Ottawa Health Science Network-REB exempted this project from review as pursuant to Tri-Council Policy as the project falls within the context of quality initiative, quality improvement, quality assurance and/or program evaluation; the project was registered as a Quality Improvement Project (QI-187) at the UOHI. In late November 2023, the project received a certificate of ethics approval (H-11-23-9946) from the University of Ottawa Office of Research Ethics and Integrity.

4.6 Data Analysis

Descriptive statistics were used to ascertain the means, medians, frequency of the study population and various sub-samples of the population. This enabled within-person (i.e., within subjects) and between-group differences to be elucidated. Building upon trends seen at the descriptive statistics level, bivariate analysis for categorical variables and continuous variables (via linear/logistic regression or ANOVA where appropriate), was carried out within the various sub-samples to assess the association of several variables in relation to PLOS, readmission, 30-day mortality, and SF-12 (PCS and MCS-12) score. Next, statistically significant predictor variables were included in multivariable ordinary least squares regressions whereby predictive models were developed to model the relationships between the key study outcome variables and predictor variables; this process is an adaptation of a prior approach by Benuzillo and colleagues (Benuzillo et al., 2018). A stepwise Bayesian Information Criterion (BIC) backward regression procedure was carried out whereby significant predictor variables (at the bivariate level) were removed one by one to assess changes to model fit in their absence; the predictor variable was removed entirely from the model if model fit improved without them as evidenced by a decrease in BIC. This process was adapted for the purposes of this study from previous work by Karim and colleagues (Karim et al., 2017); the BIC procedure was selected owing to its tendency to select the 'correct' model with a focus on selecting lesser predictors (Chakrabarti & Ghosh, 2011). Predictor variables were assessed for multi-collinearity via examining variance inflation factor (VIF) values (see Appendix). To assess statistical significance of differences with respect to SF-12 scores (PCS and MCS), Wilcoxon signed rank test (paired samples), and Wilcoxon rank sum test (unpaired samples) was utilized owing to non-normal distribution of these scores seen via Shapiro-Wilk normality testing. SF-12 change score differences were assessed via a non-parametric approach comparing ranked change scores known as Quade's test (Conover & Iman, 1982). This method was chosen to enable control of baseline PCS-12 or MCS-12 score to allow comparison of ranked change scores between groups. Testing of differences in proportions was via two-sample z tests. Significance levels in this study were marked by asterisks as follows: $p<0.05$, *; $p<0.01$, **; $p<0.001$, ***. All statistical analyses performed in the present study were completed using R (version 4.3.2, R Foundation for Statistical Computing, Vienna, Austria).

5 Results

5.1 Description of Study Population

Table 2. Demographic Characteristics of the study population

Age (mean ± SD, range, median)	65.95 ± 9.30, 28-91, 67
Sex (N, %)	
Female	423 (19)
Male	1762 (81)
BMI (mean ± SD, range, median)	28.91 ± 5.22, 14.4-51.5, 28.3
Admission Source (N, %)	
Elective	1075 (49)
Emergency Department (ED)	238 (11)
Transfer/Acute Care	783 (36)
Other	63 (3)
STS Predicted Mortality Risk (mean ± SD, range, median)	1.31% ± 1.77%, 0.16%-25.6%, 0.778%
STS Predicted Mortality Risk Levels (N, %)	
High (≥8%)	24 (1)
Intermediate (≥4%, <8%)	76 (3)
Low (<4%)	1921 (88)
Risk Factors (N, %)	
Family History of Early Coronary Artery Disease	362 (17)
Diabetes	894 (41)
Hypertension	1871 (86)
Renal Failure	25 (1)
Smoking Status	
Current Smoker	385 (18)
Former Smoker	988 (46)
Never Smoker	767 (36)
Previous Cardiac Interventions	659 (30)
Prior MI	1226 (56)
Heart Failure	
Class I	307 (14)
Class II	308 (14)
Class III	201 (9)
Class IV	52 (2)

Demographic Information

The study population comprised of 2185 CABG patients who received care at the UOHI between February 2021 and September 2023. Of this population, 423 (19%) were females and 1762 (81%) were males. The mean age of the population was just under 66 years old (SD: 9 years, range: [28-91 years]); the median was 67 years old.

Admission sources

Almost half of the population (1075, 49%) were categorized as originating from an elective source of admission. Elective surgeries are those arising from an outpatient consultation assessment with a cardiac surgeon who deems that the patient meets the criteria for cardiac surgery (Charlebois et al., 2023). The rest of the population originated from transfers from other hospitals/acute care facilities (783, 36%), emergency department (ED; 238,11%), and other (63, 3%) admission sources such as long-term care facilities or rehabilitation units.

Predicted Risk of Mortality

The mean Society of Thoracic Surgeons Predicted Risk of Mortality (STS PROM) for the study population was 1.3% (range: [0.16% - 25.6%]). Most patients within the population were categorized as low risk (i.e., having an STS PROM less than 4%; n=1921, 88%); considerably fewer patients were categorized as medium STS PROM risk level (76, 3%) and a handful were categorized as high STS PROM risk level (24, 1%).

Risk Factors

Most patients in the study population had a known risk factor for CAD; the most prevalent of which were hypertension (1871, 86%), previously suffering a myocardial infarction (MI; 1226, 56%), and diabetes (894, 41%). With respect to smoking, most patients (1755, 82%) were non-smokers; 988 (46%) had been smokers previously whereas 767 (36%) had never smoked. The remaining patients (385, 18%) were currently smoking.

5.2 Description of Other Patient Groups

Figure 3 is a chart to assist with understanding the several groups and subsets of groups of patients in the following sections.

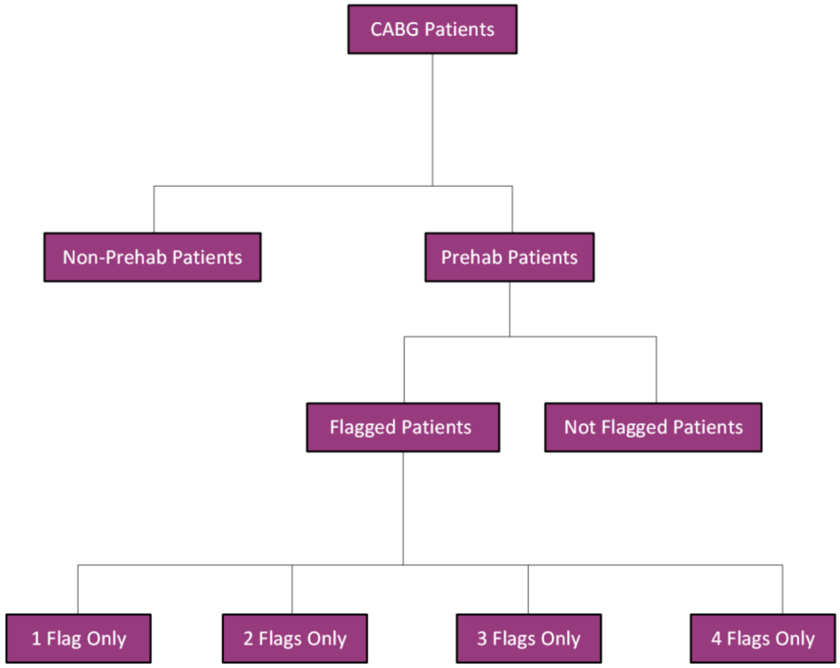

Figure 3. Tree diagram of the groups/subsets of groups of patients within this study.

Table 3. Demographic characteristics of Prehab and non-Prehab patients.

	Prehab (n=460)		**Non-Prehab (n=1468, [%])**
	Not Flagged (n=129, [%])	**Flagged (n=331, [%])**	
Demographic Factors			
Age (mean ± SD, range, median)	68.72** ± 8.34, 50-91, 70	65.78 ± 8.40, 36-87, 66	65.91 ± 9.52, 28-89, 67
Sex (N, %)			
Female	20 [16]	58 [18]	294 [20]
Male	109 [84]	273[82]	1174 [80]
BMI (mean ± SD, range, median)	29.03 ± 4.97, 20.7 – 48, 28.4	29.70 ± 5.26, 19.1 – 51.5, 29	28.54*** ± 5.22, 14.4 – 51.2, 27.9
Admission Source (N, %)			
Elective	122 [95]	318 [96]	416 [28]***
Emergency Department (ED)	1 [1]	6 [2]	225 [15]***
Transfer/Acute Care	4 [3]	5 [2]	767 [52]***
Other	2 [1]	2 [<1]	57 [4]***

STS Predicted Mortality Risk (mean ± SD, range, median)	1.09% ± 1.18%, 0.156% - 7.50%, 0.69%	0.85 ± 0.84%, 0.18% - 5.92%, 0.56%	1.49% ± 2%, 0.16% - 25.60%, 0.885%
STS Predicted Mortality Risk Levels (N, %)			
High (≥8%)	0 [0]	0 [0]	24 [2]*
Intermediate (≥4%, <8%)	3 [2]	4 [1]	68 [4]*
Low (<4%)	115 [97]	285 [99]	1299 [88]
Risk Factors (N, %)			
Family History of Early Coronary Artery Disease	20 [16]	59 [18]	241 [16]
Diabetes	40 [32]**	157 [47]	582 [40]
Hypertension	110 [87]	286 [86]	1263 [86]
Renal Failure	2 [2]	2 [<1]	14 [<1]
Smoking Status			
Current Smoker	2 [2]**	38 [11]	316 [22]***
Former Smoker	72 [56]	179 [54]	621 [42]
Never Smoker	55 [43]	114 [34]	510 [35]
Previous Cardiac Interventions	46 [36]	111 [34]	421 [29]
Prior MI	43 [33]	118 [36]	974 [66]
Heart Failure			
Class I	26 [20]	46 [14]	213 [10]
Class II	24 [19]	81 [24]	148 [10]***
Class III	14 [11]	39 [12]	119 [8]*
Class IV	2 [2]	0 [0]	47 [3]**

Note. In this table, symbols of statistical significance in the far-right column refer to differences in proportions between Prehab and non-Prehab patients. Conversely, symbols of statistical significance in the second column from the left refer to differences in proportions between flagged and not flagged patients. * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$.

From here on in, the term Prehab group refers to the group of patients who were eligible (i.e., waiting for cardiac surgery and considered a non-emergency case) for and enrolled into the Prehab automated follow up (AFU) program and had also completed their SF-12 surveys (via IVR call) at both the 1st day post Prehab AFU enrollment and three months post-discharge timepoints. The median age of Prehab patients (n=460) was 67 (range: [39 – 91]) years old, and approximately 17% were female. Most Prehab patients were categorized as elective patients (95%); the remainder were evenly split between ED (2%) and/or transfer/acute care sources (2%). No Prehab patients were deemed to be high risk as per STS-PROM conventions, approximately 1.5% were at an intermediate STS-PROM risk level and the remainder were categorized as low STS-PROM risk. With respect to risk factors, most patients (86%) had hypertension, 43% had diabetes, and 17% had a family history of early CAD. In terms of smoking status, 9% of patients smoked, 55% were former smokers and the remaining 37% had never smoked.

The patients who were categorized as non-Prehab patients were all those who were not enrolled in the Prehab AFU program at the UOHI prior to their CABG surgery within the study period. The mean age of these patients (n=1468) was 65.91 (range: [28-89]) years old, and one-fifth were females. Most non-Prehab patients were transferred from another hospital or acute care facilities (52%); the remainder of patients originated from elective (28%) or ED sources (15%). All STS-PROM high risk patients (24) in the study population were non-Prehab patients, approximately 4% were at an intermediate STS-PROM risk level and the remainder were low STS-PROM risk. In terms of risk factors, most patients (86%) had hypertension, 40% had diabetes, and about 16% had a family history of early CAD. Approximately 22% of patients smoked, 42% of patients were former smokers, and the rest (35%) had never smoked.

The inclusion criteria for categorization into the ‘flagged group’ was inclusion into the Prehab group as well as having a negative response to one or more IVR questions at the 1st day post Prehab AFU program enrollment timepoint. As their negative response raised a flag within the IVR system at this timepoint, they will be referred to collectively as the ‘flagged group’ henceforth. The median age of patients (n=331) was 66 (range: [36-87]) and 18% were females. Almost all patients were categorized as elective (96%), and the rest were almost evenly split between ED and transfer/acute care sources. No patients were categorized as STS-PROM high risk, 4 were intermediate STS-PROM risk level, and the rest were low STS-PROM risk. Most patients had hypertension (86%), almost half had diabetes (157), and 18% had a family history of early CAD. Regarding smoking status, just over 10 % (38) were smokers, just over half (179) had been smokers previously, and about one-third (114) had never smoked.

The inclusion criteria for categorization into the ‘not flagged group’ was inclusion into the Prehab group as well as having no negative responses to any IVR questions at the 1st day post Prehab AFU program enrollment timepoint; these patients are collectively referred to as the ‘not flagged group’ henceforth. The median age of patients in this group (n=129) was 70 (range: [50 – 91]) years old while 20 patients were female. Most patients (122) were elective cases; four patients came from another hospital or acute facility and the rest came from ED sources. Most patients (115) were categorized as low STS-PROM risk; three were intermediate and no patients were in the high STS-PROM risk group. In terms of risk factors, most patients had hypertension (87%), almost one-third had diabetes (40 patients), and about one-sixth (20 patients) had a family history of early CAD. The most common smoking status was former smoker (56%), followed by those who had never smoked (43%); two patients were currently smoking.

5.3 Interactive Voice Response (IVR) System Trends

5.3.1 IVR Trends Across All Timepoints for Study Population

The IVR system utilized within the Prehab AFU program calls patients throughout their patient journey at the UOHI from prior to surgery screening (i.e., within the AFU program) up to 1-year post-discharge. All patients who undergo a cardiac surgery, including CABG, at the UOHI are eligible to be enrolled into the IVR system, regardless of attending Prehab AFU program prior to surgery (i.e., emergency cases that required urgent surgery); those who do not enter the AFU program at the Prehab phase can still enter the program after discharge. To better understand the overall trends of IVR utilization within the Prehab AFU program, Figure 4a shows a breakdown IVR calls by response categories (i.e., how patients responded to the IVR call) at each timepoint for all patients within the study population.

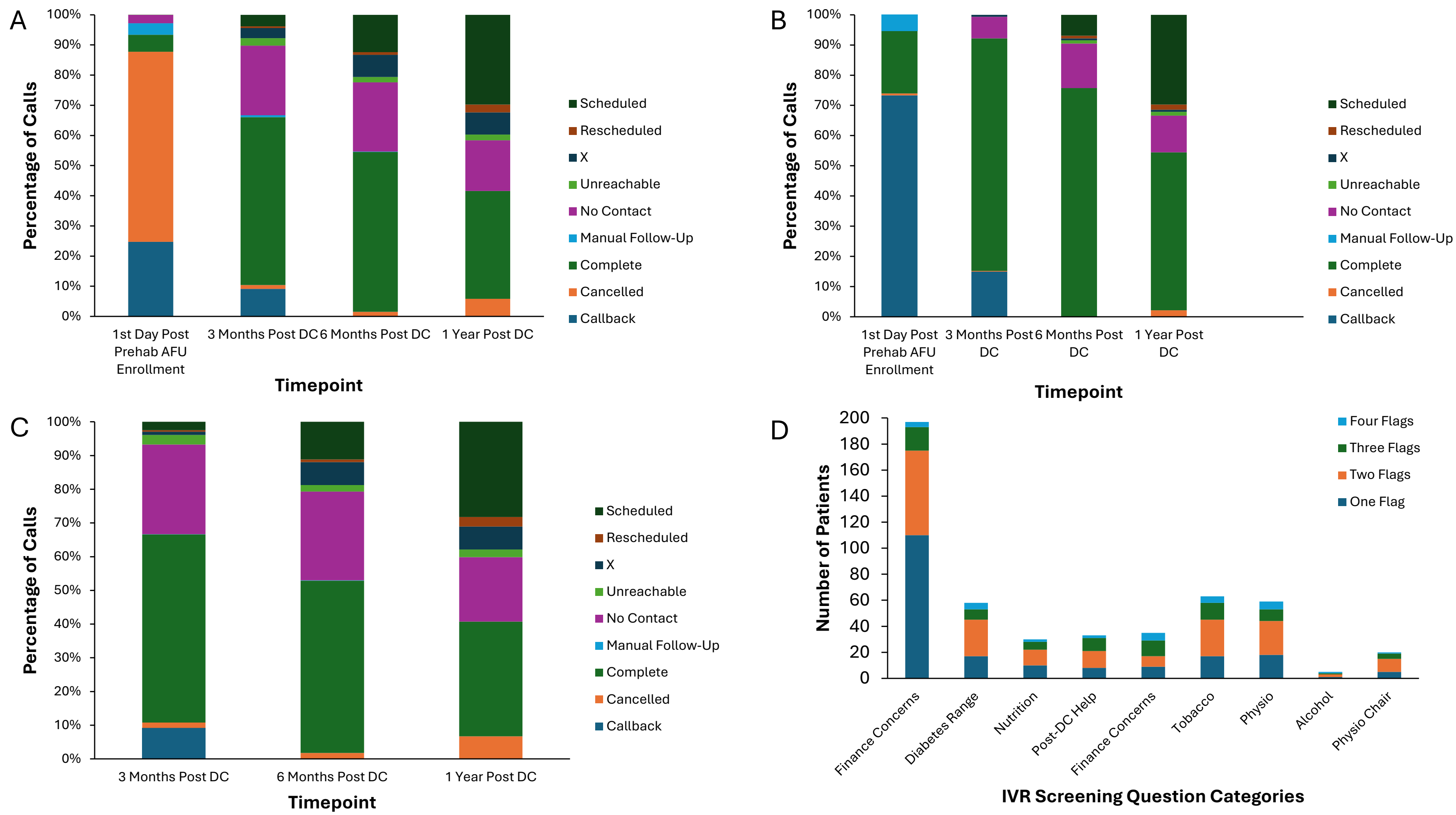

Figure 4. IVR trends for the study population between February 2021 and September 2023. (A) IVR call response category percentage at each timepoint for the study population, (B) for the Prehab group (n=460), and (C) for the non-Prehab group (n=1468). (D) Comparison of number of flags raised within the IVR system by screening question for the flagged group (n=331). DC; discharge.

There are some key takeaways from Figure 4a that are important to consider. However, this requires better understanding the definitions of call responses not previously described.

- Cancelled calls are cancelled at that timepoint either by the AFU IVR system (see explanation regarding data artifact below) or by a team member.
- Manual follow-up (i.e., Manual F/U) calls are calls that required manual calling by a team member to ascertain answers to the IVR algorithm queries; these usually occurring after a failed attempt at reaching a patient via the AFU IVR system.
- Complete calls are calls that were completed entirely via the AFU IVR system solely and do not require intervention from the team as patient responses did not flag an issue.
- No contact calls are calls that had three failed attempts to reach a patient within a 48-hour period.
- Unreachable calls are instances whereby the patient cannot be reached at the number provided, usually indicating a wrong or cancelled number etc.
- Rescheduled calls indicate a change in calling schedule was made and scheduled calls are calls slated to happen in the future.

With respect to Figure 4a, it is important to note that the large proportion of cancelled calls at the 1st day Post Prehab AFU program enrollment are an artifact of including CABG patients into the system post surgery; the system is set up in a manner whereby it assumes that all patients included in the IVR system are Prehab patients, even if patients are only added into the system after their surgery date. Secondly, the IVR system does not continue with symptom monitoring past the 3-month post-discharge timepoint. As such, the overall proportion of callbacks is artificially deflated when comparing across all timepoints. Therefore, when keeping this information top of mind, most calls across all study timepoints were categorized as complete, indicating that most calls within the AFU program were completed in an automatic manner by the patient only and did not require any manual intervention on behalf of the AFU program clinical team. The next common call response type was no contact whereby the system was unable to reach a patient despite trying thrice in 48 hours, and the third most common call designation was scheduled, indicating that a considerable number of patients in the study population have not completed their entire patient journey with regards to the IVR system at the UOHI (i.e., did not complete their calls within the system as the call dates for certain timepoints are still in the future and occurred past September 2023 which was the end date for the cohort included in this study). These trends are more obvious when described at each timepoint as is discussed in the next section.

At the 1st day post-Prehab AFU program enrollment timepoint, cancelled calls make up more than half of the recorded call response types. As mentioned in the previous section, this is a byproduct of adding patients later to the IVR system (i.e., non-Prehab CABG patients) which results in having their first call listed as cancelled even though they were never supposed to be scheduled in the system to receive a call by the system prior to surgery. From the 3-months after discharge call and onwards, all patients who underwent CABG at the UOHI received IVR calls; this includes emergency cases who underwent CABG surgery without enrolling into the Prehab AFU program prior to surgery. The most common categorizations of calls at this time were complete (56%), followed by 23% of calls resulting in no contact and 9% listed as callbacks. As at the previous timepoint, most 6-month post discharge calls were complete (53%), followed by 23% of calls being no contact and 12% were scheduled to occur in the future. At the year mark, most calls were complete (36%), closely followed by scheduled (30%) and no contact (17%). However, these trends are heavily influenced by patients who were not enrolled in the Prehab AFU program prior to surgery. As such, the following sections break down these trends further by isolating and analyzing the IVR trends for Prehab patients and non-Prehab patients separately.

5.3.2 IVR Trends Across All Timepoints for Prehab Group

At the 1st day post-Prehab AFU program enrollment timepoint, most calls (73%) of calls were listed as callbacks, indicating a substantial proportion of patients required a call back from a Prehab AFU program nurse to discuss their health further (Figure 4b). The remainder were listed as complete (21%), requiring manual follow up (5%), and 3 were cancelled. As a reminder, calls were listed as callbacks when patients self-reported negative response(s) to question(s) posed to them by the IVR system, which signals to the clinical team that follow up is required; these patients comprise the flagged group. The flags that the flagged group raised are broken down in greater detail in Figure 4d.

The flagged group (n=331) raised a combined 510 flags (Figure 4d). As such, this suggests that the average Prehab patient who is flagged by the IVR system will, on average, express more than one concern. Most flags at this timepoint were raised by the symptom screening question, indicating patient concerns relating to increased pain or pressure in the chest area. This information regarding the number of flags raised per patient is relevant to later sections as it allows for the examination of the hypothesis where those with more flags are expected to have worse SF-12 scores and post-operative outcomes.

At the 3-month post discharge mark, most calls were complete (86%); 12% were callbacks and four calls required manual follow up (Figure 4d). At the 6-month post discharge timepoint, most calls were complete (76%), followed by no contact (15%) and scheduled (7%). At the last timepoint, 52% of calls were complete, followed by scheduled (30%) and no contact (12%). This analysis is furthered by comparing within the Prehab group between flagged and not flagged patients' post-surgery. As seen in the below table, these groups were quite similar except for differences within the proportion of callback and complete calls at 3 months. The flagged group had a lower proportion of complete calls, and a higher proportion of callback calls than the not flagged group; these differences were statistically significant ($P<0.01$). This signals that at this 3-month post-discharge timepoint, flagged patients appeared to have more concerns about their health than not flagged patients.

Table 4. IVR call responses for flagged and not flagged patients at 3 timepoints post-discharge.

IVR Call Responses (%)	**Flagged**	**Not Flagged**	**Flagged**	**Not Flagged**	**Flagged**	**Not Flagged**
	3 Months Post-Discharge		6 Months Post-Discharge		1 Year Post-Discharge	
Cancelled	0	0	0	0	2.11	2.33
Complete	84.29	95.35**	75.83	75.97	54.38	47.29
Manual Follow-up	0.91	0	0	0	0	0
No contact	0	0	15.41	13.18	12.39	11.63
Unreachable	0	0	1.21	0.78	1.51	0.78

Rescheduled	0	0	1.21	0	1.81	1.55
Scheduled	0	0	6.95	10.85	28.40	37.21

Note. ** P < 0.01.

5.3.3 IVR Trends Across All Timepoints for non-Prehab Group

As mentioned previously, those not enrolled in the Prehab AFU program did not receive an IVR call prior to surgery (Figure 4c). At the 3-month post discharge timepoint, most calls were listed as complete (55%), followed by no contact (26%) and callbacks (9%). At the 6-month mark, most calls were either complete (51%), no contact (26%), and scheduled (11%). At the last timepoint, the most common categories of calls were complete (34%), closely followed by scheduled (28%) and no contact (19%).

5.3.4 Differences in IVR Trends Between Prehab & non-Prehab Patients

The proportion of IVR call responses for these groups are highlighted in the below table.

Table 5. IVR call responses for Prehab and non-Prehab patients at 3 timepoints post-discharge.

IVR Call Responses (%)	**Non-Prehab (n=1468)**	**Prehab (n=460)**	**Non-Prehab (n=1304)**	**Prehab (n=428)**	**Non-Prehab (n=1054)**	**Prehab (n=323)**
	3 Months Post-Discharge		6 Months Post-Discharge		1 Year Post-Discharge	
Cancelled	1.61	0	1.99	0	9.29	3.09
Complete	56.84	86.30***	57.52	81.54***	47.44	74.61***
Manual Follow-up	0.77	0.87	0.15	0	0	0
No contact	27.09	0***	29.60	15.89***	26.66	17.34***
Unreachable	2.86	0	2.22	1.17	3.13	1.86

Rescheduled	0.49	0	0.84	0.93	3.98	2.48
Scheduled	2.45	0	11.17	6.96	28.20	29.78

Note. *** P < 0.001.

The proportion of complete calls was greater for the Prehab group (n=460) when compared to the non-Prehab group (n=1468) at 3 months post-discharge (86.30% vs. 56.84%), 6 months post-discharge (81.54% vs. 57.52%), and 1-year post-discharge (74.61% vs. 47.44%) respectively (all differences were significant at P<0.001). Also, the proportion of calls where contact was not able to be established with the patient (i.e., no contact calls) was lower for Prehab group than the non-Prehab group at 3 months post-discharge (0% vs. 27.09%), 6 months post-discharge (15.89% vs. 29.60%), and 1-year post-discharge (17.34% vs. 26.66%) respectively (all differences were significant at a P<0.001). However, the difference in proportion of callback calls was not statistically significant at the 3-month post discharge mark (12.39%, Prehab vs. 9.36%, non-Prehab; this is the only timepoint where both groups have callbacks calls as these end after 3 months post-discharge). In summary, these trends imply a difference between Prehab and non-Prehab patients with respect to their adherence/use of the IVR system. However, the lack of difference in the proportion of callback calls between the groups indicates that both groups have similar proportions of patients with concerns regarding their health at the 3-month post-discharge timepoint.

5.4 Short Form 12 (SF-12) Health Survey Scores

5.4.1 SF-12 scores for all patients at all timepoints

To assess changes in patient HRQOL before and after surgery, the following sections indicate SF-12 scores over four timepoints throughout the patient journey. The SF-12 scores for all patients who successfully completed all SF-12 questions at any of the four main study timepoints are as follows:

Table 6. SF-12 scores for all completed surveys across all timepoints.

Timepoint / Measure	1st Day Post-Prehab AFU enrollment (n=709)	3-month post-DC (n=1323)	6-month post-DC (n=1133)	1-year post-DC (n=765)
PCS-12				
Mean ± SD	37.87± 10.24	43.17 ± 10.09	45.99 ± 10.09	46.39 ± 10.50
Median	37.35	44.22***	48.53***	49.68
MCS-12				
Mean ± SD	53.95 ±9.04	54.72 ± 8.50	53.74 ± 8.70	54.09 ± 8.70
Median	56.47	57.71*	56.77***	57.15

Note. In this table, * refers to statistically significant differences in the median score between the timepoint with the * and the preceding timepoint. * $P < 0.05$, *** $P < 0.001$.

With respect to Table 6, it is important to note a couple of key points. Firstly, this table includes all patients who were enrolled into the Prehab AFU program during the study period. This includes patients that are excluded from the group of patients who are referred to as the Prehab group within this study for not having completed their 3-month SF-12. Secondly, the 3,6 month and 1-year timepoints include patients who were not enrolled into the Prehab AFU program before their surgery and were only included post-discharge. As such, the table serves as a brief overview of the SF-12 scoring trends seen within the entire study population. The median PCS-12 score significantly differed between the 1st day post Prehab AFU enrollment and the 3-month post-discharge timepoint and between the 3 and 6-month post-discharge timepoints; the median PCS-12 score between the 6-month and 1-year timepoint did not significantly differ. For the MCS-12, there were statistically significant differences in median MCS-12 score between the 1st day post Prehab AFU enrollment and 3-month timepoint, and between the latter and the 6-month timepoint. However, the inclusion of non-Prehab patients here might obfuscate the situation; as such, the scoring for Prehab patients is isolated in the following sections.

5.4.2 SF-12 scores for Prehab group patients

For this group of patients (n=460), SF-12 scores were collected at a minimum of two timepoints (i.e., 1st day Post-prehab AFU program enrollment and 3 months post discharge). Some of these patients were further along in their patient journey and the scores for these patients that also completed the 6 months post-discharge call (n=333), and the 1-year post-discharge call (n=205) are included in Figure 5.

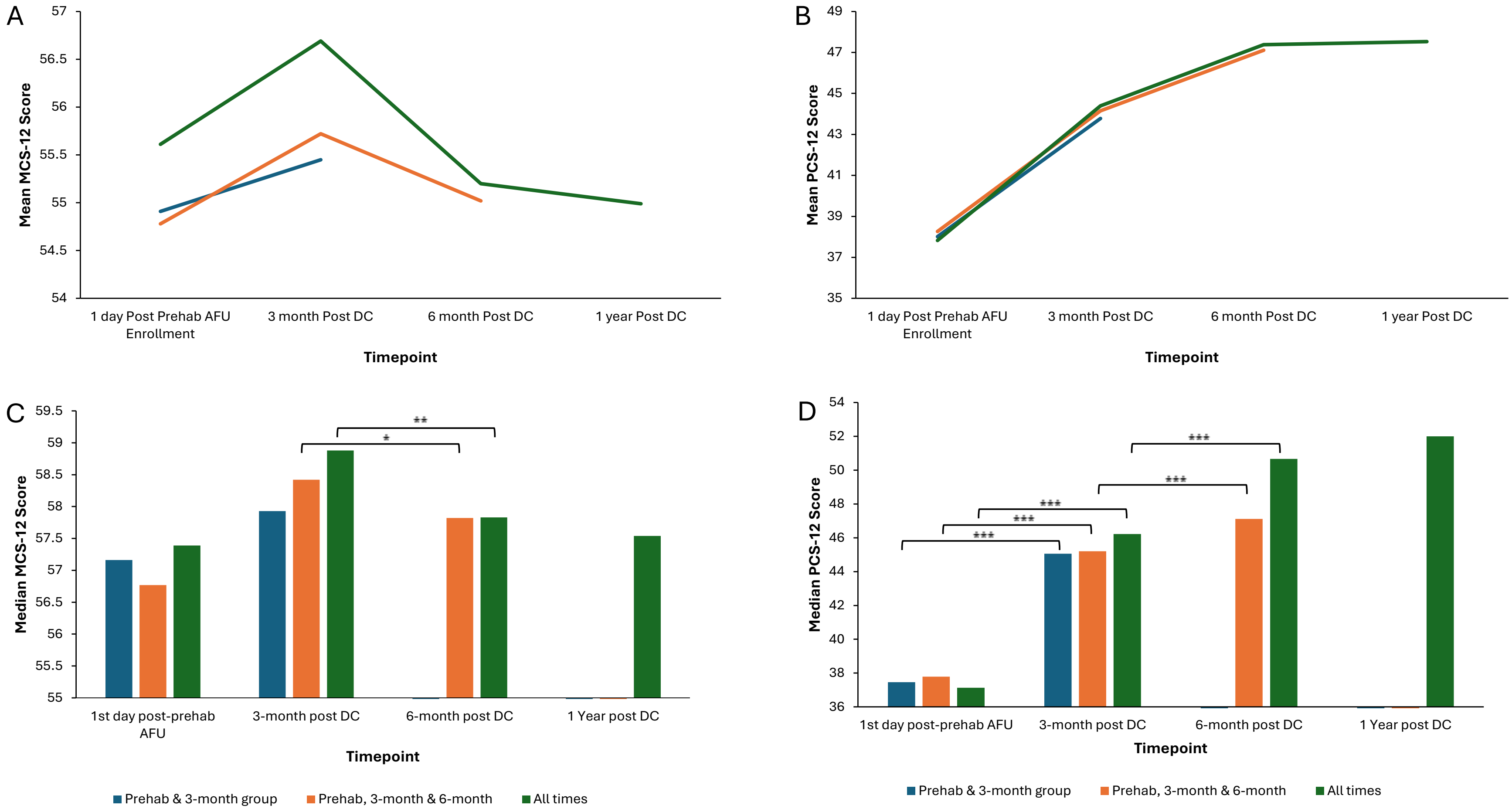

Figure 5. SF-12 scores over time for three Prehab AFU patient groups. (A) Mean MCS-12 scores. (B) Mean PCS-12 scores. (C) Median MCS-12 scores. (D) Median PCS-12 scores. * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$. DC; discharge.

For the group of patients that completed the SF-12 at the first two timepoints (i.e., the Prehab group), the difference in median PCS-12 score (Figure 5d) between the timepoints was statistically significant (P<0.001), but the difference in median MCS-12 score was not. For the group that completed the SF-12 at the first three timepoints (i.e., the Prehab, 3 and 6-month group) the difference in median PCS-12 score was statistically significant between the 1st Day Post-Prehab AFU enrollment and 3-month timepoints (P< 0.001) , as well as between the 3 and 6-month timepoints (P<0.001); the difference in median MCS-12 score was only significant between the 3 and 6-month timepoints (P=0.036). With respect to the group of patients that had completed their entire patient journey, the difference in median PCS-12 was statistically significant (P< 0.001) between all timepoints in a chronological order except for between the 6-month and 1-year timepoints; the difference in median MCS-12 score was only statistically significant (P=0.0014) between the 3-month and 6-month timepoint for this group.

5.4.3 SF-12 scores of flagged and not flagged Prehab group patients

A total of 331 patients completed the SF-12 questions at both the 1st day post Prehab AFU enrollment and 3-month post-discharge timepoint (out of a total of 460 possible) and raised flags with their responses at the 1st day post Prehab AFU enrollment timepoint (i.e., the flagged group). Their counterparts are the previously described not flagged group (n=129). The differences between these groups are displayed below.

Table 7. SF-12 scores across two timepoints for flagged and not flagged patients within the Prehab group.

Measure	Not flagged (n=129)	Flagged (n=331)
1st day post-Prehab AFU enrollment MCS-12		
Mean ± SD	56.83 ± 6.93	54.16 ± 8.80
Median	57.74	56.68**
3 Month post discharge MCS-12		
Mean ± SD	57.12 ± 5.66	54.80 ± 8.45
Median	58.58	57.83

1st day post-Prehab AFU enrollment PCS-12		
Mean ± SD	39.06 ± 10.04	37.61 ± 10.50
Median	38.84	36.91
3 Month post discharge PCS-12		
Mean ± SD	46.28 ± 9.30	42.81 ± 10.14
Median	48.58	43.37***
Δ MCS median	1.45%	2.03%
Δ MCS mean	0.51%	1.18%
Δ PCS median	25.08%	17.50%
Δ PCS mean	18.48%	13.83%

Note. Change in mean/median indicated by Δ. * Represents differences between groups at one timepoint. ** P<0.01, *** P < 0.001.

In addition to between groups differences between these groups, within groups differences are highlighted below:

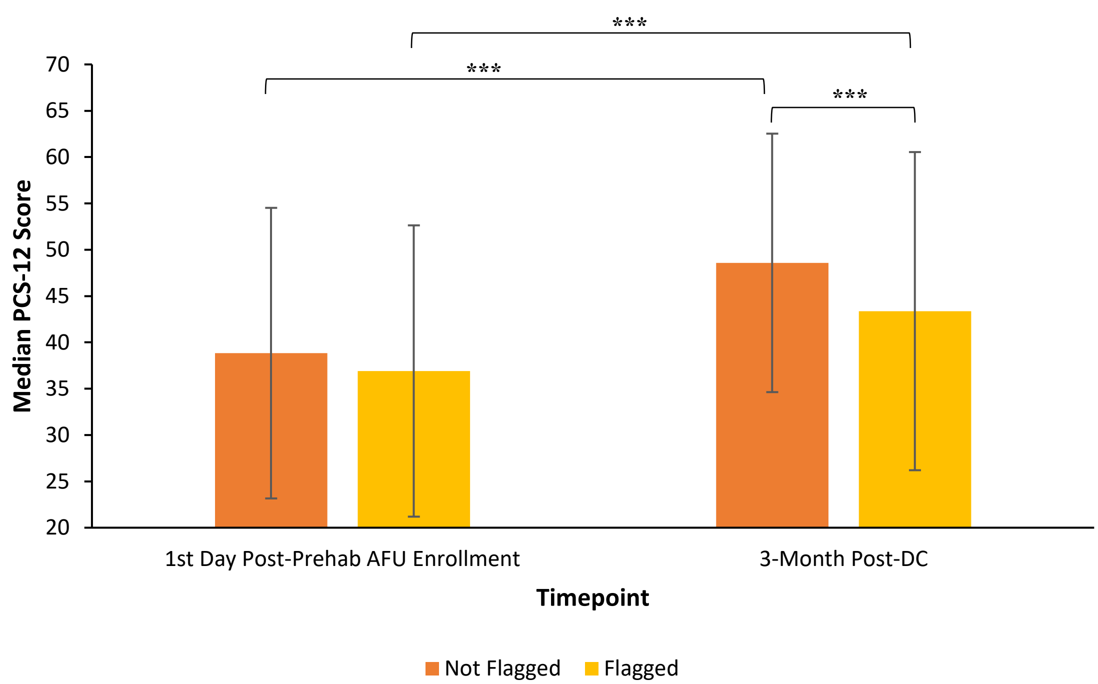

Figure 6. Median PCS-12 scores across two timepoints for flagged and not flagged Prehab group patients. Error bars indicate inter-quartile range. Statistical significance seen via Wilcoxon Signed Rank Test. *** P<0.001.

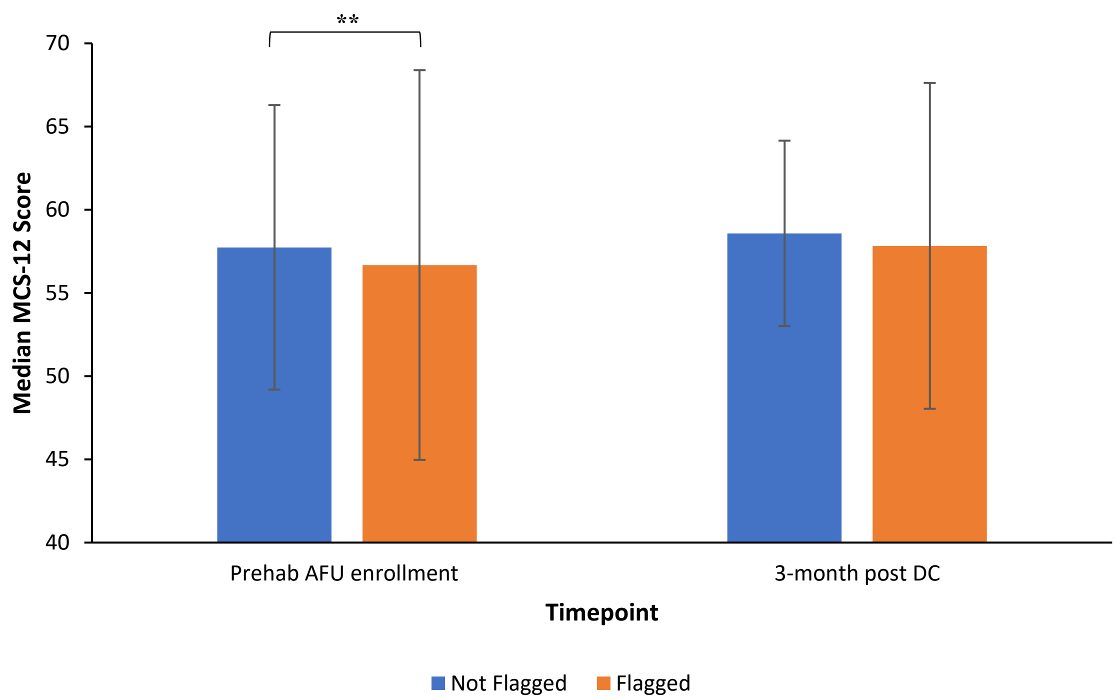

Figure 7. Median MCS-12 scores across two timepoints for flagged and not flagged Prehab group patients. Error bars indicate inter-quartile range. Statistical significance seen via Wilcoxon Signed Rank Test. ** P<0.01.

Figures 6, 7 and Table 7 highlight the contrast in scoring trends between these groups. At the 1st day post-prehab AFU enrollment timepoint, the not flagged group had a higher median MCS-12 score by approximately 1 point than the flagged group (statistically significant at P=0.0077). However, the difference in PCS-12 scores at this timepoint of almost two points was not statistically significant due to similar interquartile range (IQR). At the 3-month post-discharge timepoint, this trend was reversed. The not flagged group had a higher median PCS-12 score by over 5 points when compared to the flagged group (statistically significant at P<0.001). However, the almost 0.8 points difference in median MCS-12 scores favouring the not flagged group was not statistically significant at this timepoint.

Within groups, both groups had a statistically significant difference in their respective median PCS-12 scores when comparing across the 1st day post Prehab AFU enrollment and 3-month post-discharge timepoint; the difference in median MCS-12 scores was not. With respect to percentage change of SF-12 scores within a group, the flagged group had a 17.50% increase in the median PCS-12 score and 2.03% increase in the median MCS-12 score between the 1st day post Prehab AFU enrollment and 3-month post-discharge timepoint; this is contrasted with a 25.08% increase in median PCS-12 and 1.45% increase in median MCS-12 score for their not flagged counterparts. To examine this difference in change scores further, a non-parametric procedure allowing for statistical control of baseline scores (Quade's ANCOVA) was conducted on the change scores to examine the effect of being flagged/not-flagged on SF-12 scores at 3 months. With respect to change scores, there were no statistically significant differences between flagged and not flagged groups via Wilcoxon testing for both MCS-12 and PCS-12. Rank-biserial correlation testing of the change scores indicated that for both PCS-12 (r= -0.83) and MCS-12 (r= -0.77), the change scores of the not flagged group were ranked higher than their flagged counterparts. To evaluate these ranked change scores further, non-parametric ANCOVA revealed the following insight. While controlling for baseline PCS-12 or MCS-12 scores, being flagged/not flagged did not have a statistically significant effect on ranked change scores. Instead, this implies that baseline PCS-12 and MCS-12 score (P<0.001) had a statistically significant effect on ranked change scores. To extend this analysis further, the flagged and not flagged patients that completed the 6 months and 1 year SF-12 surveys were examined in a similar vein.

Table 8. Comparison of SF-12 scores between flagged and not flagged patients at 6 months and 1-year post-discharge.

SF-12 scores (median)	**Flagged (n=240)**	**Not Flagged (n=93)**	**Flagged (n=175)**	**Not Flagged (n=60)**
	6 Months Post-Discharge		**1 Year Post-Discharge**	
PCS-12	49.58	51.68*	51.12	52.11
MCS-12	57.14	58.00*	56.87	57.83*

Note. * P < 0.05.

At 6 months, the not flagged group (n=93) had a higher median PCS-12 and MCS-12 than the flagged group (n=240). These differences were statistically significant via Wilcoxon testing (PCS-12, P=0.033; MCS-12, P=0.017). However, the baseline MCS-12 scores did not differ in a statistically significant way; only the baseline PCS-12 score had a statistically significant difference via Wilcoxon testing (P=0.02045). Analysis of the change scores between baseline and scores at the 6 months timepoint indicated that there was no statistically significant difference in PCS-12 or MCS-12 change scores between the groups at this timepoint. Rank-biserial correlation testing indicated a tendency for the PCS-12 (r= -0.77) and MCS-12 (r= -0.80) change scores of the not flagged group to rank higher than those of the flagged group. These ranked change scores were further examined via non-parametric ANCOVA. While controlling for baseline MCS-12 or PCS-12 score, being flagged/not flagged did not have a statistically significant effect on ranked change scores for these patients. This implies that the baseline PCS-12 and MCS-12 (both P<0.001) score had a statistically significant effect on ranked change scores.

At 1-year post-discharge, the not flagged group (n=60) had a higher median MCS-12 than the flagged group (n=175); this difference was statistically significant (P=0.027). There was no statistically significant difference between the groups at this timepoint with respect to PCS-12 scores. These groups were compared at baseline, but no statistically significant differences were noted. Analysis of change scores between the 1st day post Prehab AFU enrollment and the 1-year timepoint indicated no statistically significant differences in PCS-12 or MCS-12 change scores between groups. Rank-biserial correlation testing revealed that MCS-12 (r= 0.072) change scores of the flagged group were ranked higher than those of the not flagged group, but the opposite was seen for PCS-12 (r= -0.97) change scores that indicated the change scores of the flagged group tended to be higher. When controlling for baseline MCS-12 and PCS-12 scores, non-parametric ANCOVA indicated that being flagged/not flagged did not have a statistically significant effect on ranked change scores. As such, this hints at baseline MCS-12 (P=0.0033) and PCS-12 (P<0.001) having a statistically significant effect on ranked change scores.

To examine if the number of flags that a flagged group patient raised was associated with SF-12 scores, the flagged group patients were stratified. A total of 195 patients raised one flag only, 101 raised two flags each, 27 raised three flags each, and 8 patients raised four flags each. Despite differences, albeit minor, in median PCS and MCS-12 scores, the difference between any combination of two of these groups was not statistically significant when comparing across groups at either the 1st day post-Prehab AFU program enrollment or 3-months post-discharge timepoints. As such, SF-12 scores are not associated with the number of flags raised; specifically, that it does not appear that raising more flags is associated with worse SF-12 score as was previously hypothesized. To investigate this further, modelling was conducted for flagged and not flagged patients at 3,6 months and 1-year post-discharge. Flagged or not flagged patients at these timepoints were combined, and a regression analysis was performed. These models are highlighted in the regression analysis section (see *Prehab Group Modelling*).

5.4.4 SF-12 for non-Prehab patients

Patients that did not enter the Prehab AFU program prior to surgery (i.e., the non-Prehab group) owing to the urgency of their procedures were enrolled into the AFU program once discharged from the hospital. As such, these patients could complete the SF-12 at 3,6 months and 1-year post-discharge; the scores for patients in this group (n=1468) who successfully completed surveys are listed here.

These patients (n=869) had a median PCS-12 of 43.89 (range: [11.63 - 64.48]) and median MCS-12 of 57.43 (range: [22.99 – 72.00]) at 3 months post-discharge. At 6 months post-discharge (n=749), a median PCS-12 of 47.49 (range: [15.72 – 63.09]) and median MCS-12 of 56.66 (range: [21.63 – 70.88]) was noted. At 1-year post-discharge (n=498), a median PCS-12 of 49.07 (range: [16.46 – 65.14]) and a median MCS-12 of 57.42 (range: [18.70 – 70.48]) was seen.

These scores differ from those of the Prehab patients. At 3 months post-discharge, there were no statistically significant difference in median PCS and MCS-12 scores between these patients. At 6 months post-discharge, Prehab patients (n=333) had an almost three-point higher median PCS-12 score; this difference was statistically significant (P=0.0015). The prehab patients also had just over a 1-point higher median MCS-12 than their non-Prehab peers which was statistically significant (P=0.019). At 1-year post-discharge, prehab patients (n=205) had again an almost 3-point higher median PCS-12 score than their non-Prehab counterparts; this difference was statistically significant (P=0.034). However, MCS-12 scores were comparable, with the Prehab patients having a .12 point higher median MCS-12 than the non-Prehab patients; this difference was not statistically significant. Thus, there are differences when comparing SF-12 scores between Prehab and non-Prehab patients after surgery; these are explored further in the discussion section later.

In summation, the preceding subsections highlight differences in SF-12 score trajectory across different timepoints between groups as well as trajectories of score changes within groups thereby elucidating HRQOL changes of various groups within the study population.

5.5 Study Outcome Measures (excluding SF-12)

5.5.1 Outcome Measures for Study Population

This section highlights the study outcome measures for various groups of patients within the study population to analyze if differences exist between these groups of patients. Table 9 indicates the study outcome measures for these patients.

Table 9. Outcome Measures for the study population, Prehab, and non-Prehab group.

Outcome Measure	**Study Population** (N=2185)	**Prehab Group** (n=460)	**Non-Prehab Group** (n=1468)
Readmission	148 (7)	21 (5)	105 (7)
STS operative mortality	13 (<1)	0 (0)	6 (<1)
PLOS days (mean ± SD, range, median)	7.20 ± 5.79, 1-107, 6	6.30 ± 4.80, 2-64, 5	7.29 ± 4.91, 1-77, 6
Long PLOS (>14 days)	98 (5)	11 (2)	68 (5)
Medium PLOS (>6 days, <14 days)	885 (41)	189 (40)	722 (49)
Short PLOS (<6 days)	984 (45)	243 (53)	553 (38)

Note. PLOS, post-operative length of stay.

Out of a total of 2185 patients, 148 patients (7%) were readmitted to hospital. A total of 12 patients (<1%) passed away within 30 days of their surgery as per the STS operative mortality definition; this captures all mortality occurring during the hospitalization in which CABG is undertaken even if death occurs past 30 days, and deaths after discharge from hospital that occur within 30 days of surgery (Chan et al., 2021). With respect to the PLOS of the study population, the mean surgery to discharge stay was seven days with a standard deviation of 6 days. The shortest hospitalization within the cohort was 1 day and the longest was 107 days; the median PLOS was below the mean at 6 days. Approximately 5% (98 patients) of the population had a long PLOS (i.e., greater than 14 consecutive days), about two-fifths (885 patients) of the population had a medium PLOS (i.e., greater than 6 days but shorter than 14 days) and just under half the population (984 patients) had a short PLOS (i.e., less than 6 days).

For the Prehab group (n=460), 21 patients (5%) were readmitted to hospital and five were readmitted to the Intensive Care Unit (ICU). No patients were captured within the STS operative mortality definition. With respect to the PLOS of this group, the mean was 6.3 days (SD: 4.8, range: [2-64]), the median PLOS was below the mean at 5 days. With respect to PLOS, 11 patients (2%) had a long PLOS, about 40% (189 patients) had a medium PLOS and 243 patients (53%) had a short PLOS.

For those CABG patients not in the Prehab AFU program (n=1468), 105 patients (7%) had a hospital readmission and 22 were readmitted to the ICU. There were six STS operative mortalities. The mean PLOS was 7.29 days (SD: 4.91 days, range: [1-77]) with a median of 6 days; 68 (5%) had a long PLOS, 722 (49%) had a medium PLOS, and 553 (38%) had a short PLOS.

In summary, the information presented in this section outlines the outcome measures within the study and differences in these measures between subgroups of patients. However, to further examine the main factors that are predictive of these outcomes occurring for each subgroup, statistical control is necessary. By conducting regression analysis for each subgroup, the most significantly predictive factors for each outcome measure can be determined and the result of this analysis is displayed in the following section. Moreover, the true association between predictors and the outcome measures (PLOS, readmission, STS operative mortality and SF-12) can be ascertained by doing so.

5.6 Regression Analysis

5.6.1 Elucidating the most predictive factors for the study population

Summaries of linear/logistic regression analysis models indicating the association of demographic factors, risk factors etc. to the study outcome measures (i.e., PLOS, Readmission and STS operative mortality) are displayed below.

Table 10. Factors associated with PLOS for all patients via BIC backward elimination approach.

	PLOS		
Predictors	*Estimates*	*CI*	*p*
(Intercept)	37.53	32.91 – 42.16	**<0.001**
Age	0.08	0.06 – 0.10	**<0.001**
BMI	0.09	0.05 – 0.13	**<0.001**
Female	0.98	0.45 – 1.51	**<0.001**
Renal Failure	6.39	4.47 – 8.32	**<0.001**
Prior MI	0.31	-0.12 – 0.74	0.153
Heart Failure	1.97	1.39 – 2.56	**<0.001**
ICU Readmission	7.54	5.69 – 9.40	**<0.001**
Morbidity 0	-36.27	-40.13 – -32.40	**<0.001**
Morbidity 1	-32.03	-36.00 – -28.06	**<0.001**
Morbidity 2	-25.91	-30.25 – -21.57	**<0.001**
Procedure Category CAB	-3.48	-4.66 – -2.31	**<0.001**
Procedure Category Other	-1.94	-3.36 – -0.53	**0.007**
Observations	1966		
R^2 / R^2 adjusted	0.335 / 0.331		

Table 11. Factors associated with readmission for all patients via BIC backward elimination approach.

	Readmission		
Predictors	*Odds Ratios*	*CI*	*p*
(Intercept)	0.24	0.08 – 0.59	**0.003**
Renal Failure	4.22	1.43 – 10.81	**0.005**
IMA used	0.20	0.08 – 0.56	**0.001**
Postop Infection both	17.37	8.16 – 36.73	**<0.001**
Postop Infectious	7.30	4.46 – 11.76	**<0.001**
Morbidity 1	2.09	1.12 – 3.74	**0.017**
Observations	2124		
R^2 Tjur	0.103		

Table 12. Factors associated with STS operative mortality for all patients via BIC backward elimination approach.

	STS operative mortality		
Predictors	*Odds Ratios*	*CI*	*p*
(Intercept)	0.00	0.00 – 0.01	**<0.001**
Renal Failure	19.81	2.52 – 94.21	**0.001**
One Diseased Vessel	7.73	1.10 – 33.66	**0.014**
Second Cardiac Reoperation	15.77	0.64 – 154.72	**0.036**
Morbidity 3	149.72	6.52 – 1756.38	**<0.001**
Observations	2144		

R^2 Tjur	0.043

When examining the variables predicted by modelling to significantly influence the study outcomes for the study population, it is important to keep in mind the overall differences in health status between Prehab and non-Prehab patients.

With respect to PLOS, the three most influential contributors to increased PLOS were ICU readmission, renal failure, and heart failure. The three most influential contributors to decreased PLOS were having no major morbidity (i.e., morbidity 0), having 1 major morbidity event, and having 2 major morbidity events.

When looking at readmission, the most influential contributors to the probability of a readmission occurring were having a post operative surgical site infection (both infectious and non-infectious), having a post operative infectious surgical site, renal failure and having 1 major morbidity event. The sole protective factor was whether the procedure utilized the IMA.

In terms of STS operative mortality, having 3 major morbidity events was deemed the greatest risk factor followed by having renal failure, having a second cardiac surgery reoperation, and having one diseased vessel.

In summary, this section provides an overall view of the most predictive factors for study outcome measures apart from SF-12 scores. However, the study population includes both Prehab and non-Prehab group patients. Since these groups differed with respect to some risk factors and demographic characteristics, the following sections allow for more accurate inferences to be drawn regarding the most predictive factors for these groups as these two groups of patients are separately analyzed via regression analysis.

5.6.2 Prehab Group Modelling

Summaries of linear/logistic regression analysis models indicating the association of demographic factors, risk factors, and SF-12 scores to PLOS, Readmission and STS operative mortality are displayed below.

Table 13. Factors associated with PLOS for Prehab patients via BIC backward elimination approach.

	PLOS		
Predictors	*Estimates*	*CI*	*p*
(Intercept)	-12.09	-18.34 – -5.83	**<0.001**
Age	0.13	0.06 – 0.20	**<0.001**
BMI	0.20	0.10 – 0.30	**<0.001**
Female	2.61	1.12 – 4.10	**0.001**
Heart Failure	2.64	0.89 – 4.39	**0.003**
Grafts 4	1.52	0.34 – 2.70	**0.012**
Morbidity 2	11.66	4.17 – 19.15	**0.002**
Morbidity 3	54.36	46.85 – 61.87	**<0.001**
Procedure Category AVRCAB	5.23	2.53 – 7.92	**<0.001**
Bypass Time	0.03	0.01 – 0.04	**0.001**
Observations	217		
R^2 / R^2 adjusted	0.632 / 0.616		

Table 14. Factors associated with readmission for Prehab patients via BIC backward elimination approach.

	Readmission		
Predictors	*Odds Ratios*	*CI*	*p*
(Intercept)	0.19	0.03 – 0.91	0.051

Smoker (Unknown Frequency)	41.03	1.55 – 1086.95	**0.010**
Postop Infection both	26.14	4.78 – 135.26	**<0.001**
Postop Infectious	11.59	3.46 – 35.66	**<0.001**
Morbidity 0	0.13	0.03 – 0.75	**0.017**
Observations	461		
R^2 Tjur	0.196		

It is important to note that SF-12 scores were included as predictors in modelling for this group of patients only as the other patient groups in this section did not complete this survey prior to surgery. Although MCS-12 scores were found not to be associated with neither PLOS nor readmission, PCS-12 scores were associated with a PLOS when compared at the bivariate level in a statistically significant manner (p=0.000891). The relationship indicated that a one unit increase in PCS-12 score was associated with a 0.07 decrease in PLOS. Alternatively, an increase in PCS-12 score of just over 14 would be expected to result in a 1 day decrease in PLOS. However, when combined with the several other demographic variables or risk factors, PCS-12 scores were not included in models via BIC backward elimination. This implies that there were other predictors that were more predictive of outcomes specifically for this group.

The patients in the Prehab group were followed through their journey with the AFU program, and the SF-12 scores for the patients that completed the survey at 3,6 months and 1-year discharge were modelled. This was conducted with the aim of examining how SF-12 scores changed over time with respect to covariates. At 3 months post-discharge, SF-12 score data from 460 patients were analyzed via regression analysis with the following result.

Table 15. Factors associated with MCS-12 scores for Prehab patients at 3 months post-discharge via BIC backward elimination approach.

		MCS-12	
Predictors	*Estimates*	*CI*	*p*

(Intercept)	57.49	56.12 – 58.85	**<0.001**
Flagged	-1.41	-3.10 – 0.28	0.101
Flags 2	-1.96	-3.79 – -0.14	**0.035**
Flags 3	-3.43	-6.57 – -0.29	**0.032**
Grafts 2	-2.04	-3.75 – -0.33	**0.020**
Postop Infection both	5.93	0.53 – 11.32	**0.031**
Observations	460		
R^2 / R^2 adjusted	0.056 / 0.046		

Table 16. Factors associated with PCS-12 scores for Prehab patients at 3 months post-discharge via BIC backward elimination approach.

		PCS-12	
Predictors	*Estimates*	*CI*	*p*
(Intercept)	57.32	52.24 – 62.40	**<0.001**
Flagged	-3.13	-5.06 – -1.19	**0.002**
BMI	-0.33	-0.49 – -0.16	**<0.001**
Female	-3.49	-5.78 – -1.20	**0.003**
Smoke everyday	-4.37	-7.66 – -1.07	**0.009**
Heart Failure	-5.26	-7.93 – -2.59	**<0.001**
Postop Infection both	-8.77	-15.42 – -2.12	**0.010**
Observations	460		
R^2 / R^2 adjusted	0.136 / 0.125		

With respect to the association of MCS-12 or PCS-12 at 3 months to other factors, there were two common factors seen for both scores at 3 months. If a patient had been flagged at the 1st day post AFU program enrollment timepoint and, having a postoperative infection were found to be significantly associated with either PCS-12 or MCS-12.

At 6 months post-discharge, SF-12 scores from a total of 333 patients (240 flagged and 93 not flagged) were analyzed via regression analysis yielding the following results.

Table 17. Factors associated with MCS-12 scores for Prehab patients at 6 months post-discharge via BIC backward elimination approach.

	MCS-12		
Predictors	*Estimates*	*CI*	*p*
(Intercept)	58.58	56.73 – 60.44	**<0.001**
Flags 2	-3.72	-5.59 – -1.85	**<0.001**
Elective	-3.04	-5.03 – -1.05	**0.003**
Readmission	-5.08	-8.87 – -1.30	**0.009**
Observations	333		
R^2 / R^2 adjusted	0.084 / 0.076		

Table 18. Factors associated with PCS-12 scores for Prehab patients at 6 months post-discharge via BIC backward elimination approach.

	PCS-12		
Predictors	*Estimates*	*CI*	*p*
(Intercept)	48.61	46.89 – 50.33	**<0.001**
Flags 3	-6.04	-10.56 – -1.52	**0.009**
Female	-3.82	-6.66 – -0.99	**0.008**
Prior MI	-3.56	-5.84 – -1.28	**0.002**
HF Class III	-5.13	-8.43 – -1.82	**0.002**
CABG Off Pump	3.39	1.20 – 5.58	**0.003**
Observations	333		
R^2 / R^2 adjusted	0.100 / 0.087		

There were three predictor variables associated with MCS-12 score at 6 months post-discharge, while five predictor variables were associated with PCS-12 score at 6 months post-discharge. There was no predictor variable that was associated with both scores. Interestingly, raising two flags (vs. not belonging in that category) at the 1st day post Prehab AFU program enrollment call was seen to be associated with lower MCS-12 score at this timepoint, whereas raising three flags at the enrollment call was associated with lower PCS-12 score at this timepoint.

At 1-year post-discharge, SF-12 score data from 235 patients (175 flagged and 60 not flagged) was examined via regression analysis.

Table 19. Factors associated with MCS-12 scores for Prehab patients at 1-year post-discharge via BIC backward elimination approach.

	MCS-12		
Predictors	*Estimates*	*CI*	*p*
(Intercept)	51.95	49.72 – 54.19	**<0.001**
Three Diseased Vessels	3.36	0.88 – 5.85	**0.008**
Observations	235		
R^2 / R^2 adjusted	0.029 / 0.025		

Table 20. Factors associated with PCS-12 scores for Prehab patients at 1-year post-discharge via BIC backward elimination approach.

	PCS-12		
Predictors	*Estimates*	*CI*	*p*
(Intercept)	52.43	48.59 – 56.27	**<0.001**
Flags 3	-10.76	-17.14 – -4.38	**0.001**
Flags 4	13.02	3.08 – 22.96	**0.010**
Hypertension	-6.34	-10.23 – -2.46	**0.001**
HF Class III	-5.43	-9.32 – -1.53	**0.006**
Never Smoker	3.36	0.67 – 6.06	**0.015**
Observations	235		
R^2 / R^2 adjusted	0.164 / 0.146		

The modelling for MCS-12 did not reveal many significant predictors at the bivariate level, resulting in a small model with only one predictor which was not found in the PCS-12 model. Interestingly, the PCS-12 model indicates that raising three flags at the 1st day post Prehab AFU program enrollment call was associated with a lower PCS-12 score, and raising four flags at this call was associated with higher PCS-12 scores.

The tables below help to summarize the models for the Prehab group with respect to SF-12 modelling. Of note, no predictor variable was observed to have a statistically significant association with either PCS-12 or MCS-12 for all three post-surgery timepoints.

Table 21. Summary of MCS-12 predictive factors for Prehab patients at 3 timepoints.

MCS-12 Predictors		**3 Months Post-Discharge (n=460)**	**6 Months Post-Discharge (n=333)**	**1 Year Post-Discharge (n=235)**
Protective Factors	**Risk Factors**			
	Flagged	☑		
	Flags 2	☑	☑	
	Flags 3	☑		
	Grafts 2	☑		
Postop Infection both		☑		
	Elective		☑	
	Readmission		☑	
Three Diseased Vessels				☑

Table 22. Summary of PCS-12 predictive factors for Prehab patients at 3 timepoints.

PCS-12 Predictors		**3 Months Post-Discharge (n=460)**	**6 Months Post-Discharge (n=333)**	**1 Year Post-Discharge (n=235)**
Protective Factors	**Risk Factors**			
	Flagged	☑		
	BMI	☑		
	Female	☑	☑	
	Smoke Everyday	☑		
	Heart Failure	☑		
	Postop Infection both	☑		

	Flags 3		☑	☑
	Prior MI		☑	
	HF Class III		☑	☑
CABGOP			☑	
	Flags 4			☑
	Hypertension			☑
Never Smoker				☑

5.6.3 Non-Prehab Group Modelling

Summaries of linear/logistic regression analysis models indicating the association of demographic and other risk factors to the study outcome measures are displayed in Tables 23-25.

Table 23. Factors associated with PLOS for non-Prehab patients via BIC backward elimination approach.

	PLOS		
Predictors	*Estimates*	*CI*	*p*
(Intercept)	9.11	6.89 – 11.33	**<0.001**
Age	0.08	0.06 – 0.11	**<0.001**
Renal Failure	6.26	3.90 – 8.63	**<0.001**
Heart Failure	1.92	1.31 – 2.53	**<0.001**
ICU Readmission	7.82	5.85 – 9.79	**<0.001**
Morbidity 0	-4.20	-5.16 – -3.24	**<0.001**
Morbidity 3	18.96	10.47 – 27.45	**<0.001**
Procedure Category CAB	-3.99	-5.28 – -2.70	**<0.001**

Procedure Category Other	-2.29	-3.91 – -0.68	**0.005**
Observations	1343		
R^2 / R^2 adjusted	0.239 / 0.235		

Table 24. Factors associated with readmission for non-Prehab patients via BIC backward elimination approach.

	Readmission		
Predictors	*Odds Ratios*	*CI*	*p*
(Intercept)	0.36	0.12 – 0.93	**0.048**
Renal Failure	6.32	1.63 – 20.04	**0.003**
IMA used	0.15	0.06 – 0.48	**<0.001**
Postop Infection both	20.96	7.78 – 57.47	**<0.001**
Postop Infectious	7.14	3.90 – 12.68	**<0.001**
Observations	1445		
R^2 Tjur	0.086		

Table 25. Factors associated with STS operative mortality for non-Prehab patients via BIC backward elimination approach.

	STS operative mortality		
Predictors	*Odds Ratios*	*CI*	*p*
(Intercept)	0.00	0.00 – 0.01	**<0.001**
Renal Failure	38.68	1.84 – 330.93	**0.002**
One Diseased Vessel	16.11	1.83 – 108.01	**0.005**
CABGMVST	9.99	0.43 – 90.07	0.069

Observations	1446
R^2 Tjur	0.055

With respect to PLOS, the three most influential contributors to increased PLOS were having 3 major morbidity events, ICU readmission, and renal failure. The three most influential contributors to decreased PLOS were having no major morbidity (i.e., morbidity 0), having an isolated CABG procedure, or having a type of procedure that was deemed not to be traditional CABG or CABG and valve repair surgery.

In terms of readmission for this group, the most influential contributors to the possibility of readmission were having a post operative surgical site infection (both infectious and non-infectious), having a post operative infectious surgical site, and renal failure. Utilization of the IMA was deemed to be a protective factor against readmission in this model.

With regards to STS operative mortality, renal failure was the greatest risk factor, followed by having one diseased vessel, and undergoing a multi-vessel small thoracotomy (MVST).

In summary, the preceding subsections described the most predictive factors for the general study population as well as when focusing on patients based on Prehab enrollment status. The differences in the most predictive factors between the Prehab and non-Prehab group indicate differences between these groups could be potentially attributed to the difference in their enrollment in the Prehab AFU program prior to surgery. The tables below summarize these predictive factors for these groups allowing for easier comparison.

Table 26. Post-operative length of stay predictive factors for three patient groups.

PLOS Predictors		All Patients (n=2185)	Prehab Patients (n=460)	Non-Prehab Patients (n=1468)
Protective Factors	**Risk Factors**			
	Age	☑	☑	☑
	BMI	☑	☑	
	Female	☑	☑	
	Renal Failure	☑		☑
	Prior MI	☑		
	Heart Failure	☑	☑	☑
	4 Grafts		☑	
	ICU Readmission	☑		☑
	Morbidity 0	☑		☑
	Morbidity 1	☑		
Morbidity 2		☑ (protective)	☑ (risk)	
	Morbidity 3		☑	☑
Procedure Category CAB		☑		☑
	Procedure Category AVRCAB		☑	
Procedure Category Other		☑		☑
	Bypass Time		☑	

Table 27. Readmission predictive factors for three patient groups.

Readmission Predictors		All Patients (n=2185)	Prehab Patients (n=460)	Non-Prehab Patients (n=1468)
Protective Factors	**Risk Factors**			
	Renal Failure	☑		☑
IMA used		☑		☑
	Postop Infection both	☑	☑	☑
	Postop Infectious	☑	☑	☑

	Smoker (Unknown Frequency)		☑	
Morbidity 0			☑	
	Morbidity 1	☑		

Table 28. STS operative mortality predictive factors for two patient groups.

STS Operative Mortality Predictors	All Patients (n=2185)	Non-Prehab Patients (n=1468)
Risk Factors		
Renal Failure	☑	☑
One Diseased Vessel	☑	☑
Second Cardiac Reoperation	☑	
Morbidity 3	☑	
CABGMVST		☑

6 Discussion

6.1 IVR utilization trends

To evaluate impacts of IVR technology on patient process of care, utilization trends of the IVR system were examined. For the overall AFU program, almost 50% of all calls were completed by the patient without assistance from the clinical team and are not raising any flags for health concerns. The next largest proportion of call responses at almost 16% was calls where patients could not be reached despite being called thrice in a 48-hour period (i.e., no contact calls). This is concerning as these calls represent missed opportunities to contact patients. This adds to the resource burden for the clinical team as they must further explore the situation via a manual call to the patient. The next highest proportion of calls at just over 10% of calls (when excluding the artificially inflated number of cancelled calls prior to surgery) is the callback category where patients indicate a potential health concern. This proportion, although high, is a positive signal. This indicates that patients are being screened for a health concern automatically by the algorithm within the IVR system which is what the system is expected to do. This automation reduces resource burden on members of the clinical team, freeing them up to focus on providing care to patients who are in immediate need of their attention. Also, since the screening is already done, clinical team members know what exactly to probe patients on and can target their call towards finding out more about these specific issues. In summary, the system appears to be working as intended with respect to call response categories. However, the high proportion of no contact calls represents an area of further investigation. Patients (especially non-Prehab patients, see the following paragraphs for this explanation) could be educated further about the importance of adhering and using the IVR system as a first step towards addressing health concerns. The differences in these IVR trends between groups is highlighted below.

At all timepoints after discharge (i.e., 3,6 months and 1 year), the proportions of complete calls were higher, and the proportion of no contact calls (where the patient cannot be reached by the IVR system in a 48-hour period) were lower in the Prehab group when compared to their non-Prehab counterparts ; these differences were statistically significant ($P<0.001$). This implies notable differences between the groups with regards to their adherence to the IVR system. Despite this, differences in the proportion of the callback response category were not statistically significant. This suggests the proportion of patients having health concerns at 3 months post-discharge was not impacted by whether patients were enrolled in the AFU program during Prehab (i.e., before surgery) or enrolled post-discharge from hospital. The difference in proportion of calls where manual follow-up was required was not statistically significant, and the difference in the proportion of calls to patients deemed unreachable was only statistically significant at 3 months post-discharge ($P<0.001$) where a higher proportion of patients were unreachable in the non-Prehab group compared to the Prehab group. As unreachable calls are usually the result of entering a wrong number into the system or the number provided being out of service, this difference could have resulted as a byproduct of patient case urgency. Specifically, the clinical team may not have had the time or opportunity to verify the accuracy of contact information provided by patients; this could be more likely for those in the non-Prehab group as they are not contacted prior to surgery and as such incorrect contact information could persist within the IVR system longer. However, the proportion of unreachable calls not differing between Prehab and non-Prehab patients later in the patient journey could occur naturally. For instance, it is plausible for patients to change their numbers several months or a year after their discharge and as such a natural increase in this proportion of calls is plausible. Overall, the differences noted earlier between Prehab and non-Prehab patients with respect to adherence to the IVR system may stem from Prehab patients having experience with the IVR system before surgery. This is in line with previous research looking at IVR adherence within a larger clinical trial that suggested that IVR adherence in the early part of a year-long study was predictive of retention and completion of the remaining IVR calls (Gatehouse et al., 2012).

6.2 Examining Variations in Demographic Characteristics Across Groups

6.2.1 Comparison to prior research and across groups

The study population exhibits similar differences in the proportion of men (81%) and women (19%) as seen in previous studies; larger studies such as a 17-year single site CABG surgery only study in the United States indicated a split of 21% women to 79% men with insignificant changes in this split throughout the study duration (Matyal et al., 2021). The mean age of the study population (66 years old) is similar to previous literature such as the aforementioned study with a mean of just over 66 years old (Matyal et al., 2021). The risk profile of the study population also appears to be similar to a recent, albeit smaller study; a mean STS PROM ranging from 1.1% (non-frail) to 2.9% (frail) was reported for a study with 500 CABG patients aged 60 or older in Montreal, Canada (Solomon et al., 2021). This is comparable to the mean of the study population in the present study which was 1.31% (SD: 1.77%). In summation, the study population is similar to populations in previously published research within cardiac surgery, adding to the generalizability of results. However, there were differences between patient groups.

6.2.2 Comparing demographic characteristics across Prehab and non-Prehab patients

In this section, Prehab patients were compared to their non-Prehab counterparts with respect to demographic characteristics. Although the Prehab group was slightly older (66.59 vs. 65.78) and had a lower proportion of females (17% vs. 20%) than their non-Prehab counterparts, these differences were not statistically significant. There was a statistically significant difference (at $P<0.001$) in BMI, whereby the Prehab group had a higher BMI (29.51) than their non-Prehab peers (28.54) With respect to admission source, the Prehab group had a much higher proportion of elective patients (95% vs. 37%) and a greatly lower proportion of patients from ED (2% vs. 13%) or transfer/acute care sources (2% vs. 45%); these differences were statistically significant in all categories ($P<0.001$). This is most probably attributable to the inherent difference in Prehab and non-Prehab patients whereby non-Prehab patients require more urgent surgical intervention. In terms of PROM risk, the proportion of patients in the high (0% vs. 1%) and intermediate (1% vs. 4%) PROM risk level was lower in the between the Prehab than the non-Prehab groups respectively; these differences were statistically significant (P<0.001). However, the proportion of low PROM risk level patients was similar between the groups (87% vs. 88%). These differences in PROM levels are again most likely the result of the difference in the urgency of surgical intervention between the groups. With respect to risk factors, the proportion of patients with hypertension (86% vs. 85%), diabetes (43% vs. 40%), and a family history of early CAD (17% vs. 16%) were similar and these differences between the Prehab and non-Prehab group respectively were not statistically significant. However, there was a notable difference in smoking status. The proportion of current smokers was lower (9% vs. 20%), and the proportion of former smokers (55% vs. 43%) was higher in the Prehab than the non-Prehab group respectively (statistically significant at P<0.001). However, the difference in the proportion of never smokers (37% vs. 35%) was not statistically significant. With respect to heart failure, the Prehab group had a higher proportion of patients with class II, III heart failure compared to the non-Prehab group; these differences were statistically significant (Class II, P<0.001; Class III, P=0.03166). However, the non-Prehab group had a statistically significantly higher proportion of class IV heart failure patients compared to the Prehab group (P=0.0018). When considering the differences in smoking status and heart failure, it is reasonable to infer that these patients do indeed have some differences in factors prior to surgery. As smoking (Rogers et al., 2019) and heart failure (O'Brien et al., 2018) are known risk factors that worsen post-operative outcomes, this difference in terms of these factors between these groups might be impacting post-operative outcomes differences, if any, between these groups. In summation, there are some differences between these groups outside of the expected differences in admission source; this suggests that there are some inherent differences between these patients prior to CABG surgery. As such, this might influence post-operative outcomes and SF-12 scoring after surgery and result in differences in these between the groups; this is discussed further in the following sections.

6.2.3 Comparing demographic characteristics of flagged and not flagged patients

There were a few differences in between patients in the Prehab group. The median age for the flagged group (n=331) was younger (66 years old, range: [36-87]) than the not flagged group (n=129) (70 years old, range: [50-91]); this difference was statistically significant (P=0.0011). The proportion of males and females did not differ, nor did median BMI from the point of view of statistical significance. With respect to admission sources and PROM risk levels, no statistically significant differences were seen in between any category with almost identical proportions for the groups. In terms of risk factors, no statistically significant differences were observed between these groups except for diabetes and smoking status. There was a higher proportion of patients with diabetes in the flagged group (47%) than within the not flagged group (32%); this difference was statistically significant (P=0.0019). In terms of smoking, the proportion of current smokers was greater in the flagged group (11%) than the not flagged group (2%); this difference was statistically significant as well (P=0.0013). However, differences in proportions of former or never smokers were similar and not statistically significant. Overall, the flagged group and not flagged group appear to be quite alike in terms of demographic characteristics.

6.3 Differences in Study Outcomes

6.3.1 Differences in post-operative outcomes between Prehab and non-Prehab patients

To assess changes in patient health status/HRQOL pre-post surgery, SF-12 score changes (next section), and post-operative outcomes were analyzed for within group and between group differences. Prehab patients (n=460) and non-Prehab patients (n=1468) did not differ in a statistically significant manner with respect to the proportion of readmissions and mortality. There were, however, differences in PLOS whereby non-Prehab patients had a higher proportion of patients with a long PLOS (P=0.024) and a smaller proportion of patients with a short PLOS (P<0.001) when compared to their Prehab counterparts; these differences were statistically significant. This finding is consistent with the conclusions of a systematic review that indicated the positive impact of prehabilitation on reducing PLOS for CABG surgery patients (Olsen et al., 2023). However, in the context of the present study it is difficult to be entirely certain that this reduction in PLOS arises from Prehab interventions alone owing to Prehab patients being healthier than non-Prehab patients before surgery. However, the differences in PCS-12 scores at

6 months and 1-year post-discharge provide some evidence of differences during recovery between these patients. When the PCS-12 scores (MCS-12 was excluded owing to similarities at most points) at 3 months post-discharge were set as a dependent variable and both Prehab (n=460) and non-Prehab patient (n=869) were included in a regression model, being female, having conditions such as diabetes, class III heart failure, renal failure, smoking everyday, and having a readmission were seen as predictive factors (see appendix for estimates). The association between Prehab AFU program enrollment (dichotomized as Yes/No) and PCS-12 score at 3 months was found not to be statistically significant. As such, pre-surgery risk factor differences in between the Prehab and non-Prehab groups appear to impact 3 months post-discharge PCS-12 score rather than whether they enrolled in the Prehab AFU program prior to surgery. Nevertheless, these findings further consolidate findings in a recent study with a similar cohort of patients at the UOHI (Charlebois et al., 2023).

6.3.2 Differences in post-operative outcomes between flagged and not flagged patients

To examine differences in post-operative outcomes and HRQOL score (next section) between Prehab patients based on whether they received interventions before surgery, flagged patients (with between group analysis for number of flags raised) and not flagged patients were compared. Flagged (n=331) and not flagged patients (n=129) did not differ (differences were not statistically significant) with respect to the proportion of readmissions and PLOS. This lack of differences might be attributed to the similarity of patient health status, on average, prior to surgery. These patients collectively are healthier, on average, than their non-Prehab counterparts as previously mentioned. Moreover, flagged and not flagged patients were able to wait prior to surgery and enroll in the Prehab AFU program from the start; this difference in ability to wait in comparison to the non-Prehab patients is similar between all Prehab patients. Another possibility for the similarity in post surgery outcomes is the impact of Prehab interventions on health status. Those who were flagged or not flagged might have differed slightly in health status prior to surgery, and the combination of Prehab interventions alongside CABG for the flagged patients was able to overcome this pre-surgery difference to produce similar post-surgery outcomes. Thus, this combination of similarity in pre-surgery health status and the addition of Prehab interventions for flagged patients might be a reasonable explanation of the similarities with respect to post-surgery readmission and PLOS between these groups.

6.3.3 Differences in post-operative outcomes within flagged group split by flags raised

The flagged group of patients were also examined for differences, if any, in post-operative outcomes by separating patients into groups based on the number of flags they raised; 195 patients raised one flag, 101 raised two flags, 27 raised three, and 8 patients raised four flags. There were some differences between flagged patients when split into groups based on number of flags raised in terms of median PLOS, but none of these differences were statistically significant between any combination of two of these split by flags raised groups. Also, no statistically significant differences between any combination of two of these split by flags raised groups of patients were noted with respect to proportions of long, medium, and short PLOS. Although there were some differences in terms of readmissions, none of these were statistically significant for any combination of two split by flags raised groups of these patients. Therefore, all flagged patients had similar PLOS and readmissions. This contrasts with the previously hypothesized theory that raising more flags could be associated with worse post-operative outcomes as all patients who raised flags had similar post-operative outcomes.

6.3.4 Overview of SF-12 score trends for study population

When examining the study population, there are statistically significant increases in both median PCS and MCS-12 scores between the first day post-Prehab AFU program enrollment and the 3-month post discharge timepoints. This is most likely a result of the difference made by the CABG surgery for all patients. For Prehab patients, this difference could be attributed to Prehab interventions and CABG surgery. The median PCS-12 continues to increase in between the 3-month and the 6-month post-discharge timepoints in a statistically significant manner before recording a small difference between the 6-month and 1-year timepoints which did not reach statistical significance. This might be reflective of the average timeline for CABG recovery. Most patients start with physically undemanding activities such as walking in the first few weeks, and most resume more physically demanding activities such as yard work after 3 months of recovery (University of Ottawa Heart Institute, n.d.-c). Furthermore, the previously mentioned regression analysis with both Prehab (n=460) and non-Prehab patients (n=869) where the association between Prehab AFU program enrollment (i.e., yes/no) before surgery and PCS-12 at 3 months post-discharge was found not to be statistically significant adds to the notion that pre-operative risk factors appeared to impact more on post-operative HRQOL rather than whether patients were in the Prehab program prior to surgery. This adds to the theory whereby both sets of patients receive improvements from CABG surgery, and Prehab patients could be receiving a slightly higher percentage increase in post-operative HRQOL because of their Prehab program enrollment before surgery. In conclusion, the recovery process is gradual, and the PCS-12 scores reflect this process.

With respect to MCS-12 scores, a more unclear trend is noted. Between the 3 and 6-month post-discharge timepoints, the median MCS-12 score decreased in an almost similar amount to the increase in the previous period; the difference was statistically significant. Between the 6-month and 1-year timepoint, the median MCS-12 scores increase slightly but does not differ in a statistically significant manner to the previous timepoint. Overall, MCS-12 scores slightly improved from the pre-surgery timepoint till the 1-year post-discharge, but the MCS-12 scores were slightly down from the 3-month timepoint till the end of the study period. The inclusion of non-Prehab patients might have skewed the picture surrounding MCS-12 score as they did not complete a pre-surgery baseline MCS-12. The MCS-12 trend (and PCS-12) is elaborated on in the following sections in the Prehab group where there is a pre-surgery baseline to compare changes post-operatively.

6.3.5 Overview of SF-12 core trends for Prehab patients

The trends for the various Prehab patient groups provide an opportunity to examine the changes in both MCS and PCS-12 scores over the entirety of the patient journey with respect to the IVR system. In the Prehab group (n=460), the group who completed Prehab up to 6 months (n=333), and the group who completed the entire journey (n=205), there was a statistically significant increase ($p<0.001$) in median PCS-12 score between the 1st day post Prehab AFU program enrollment and the 3-month timepoint, and between the 3-month and 6-month timepoint for the group who completed Prehab up to 6 months and for the group who had a complete journey. The slight increase in median PCS-12 score between the 6-month and 1-year timepoints for the group that completed the entire journey was not statistically significant. As such, this increases confidence in the previously seen increase in PCS-12 score for all patients between the 3- and 6-month timepoints regardless of whether they had only completed up to 6 months or a year. Also, this indicates that the greatest percentage increase in median PCS-12 score occurs between the two timepoints straddling the CABG procedure, which indicates plateauing of the PCS-12 score later at 6 months and 1 year.

The trends for these Prehab groups, split by time completed in the patient journey, in terms of MCS-12 is clearer now that non-Prehab patients are excluded from the analysis. As such, the difference in median MCS-12 scores only differed for the group who completed 6 months (n=333) and the group who completed a year (n=205) between the 3- and 6-month timepoints. Between the 3- and 6-month timepoints, median MCS-12 score decreased for these groups. For the group who completed a year, a further decrease was seen between the 6 month and 1-year timepoint; the difference between scores at this last interval was not statistically significant. In summary, the trend for MCS-12 score from the start point and end point of the study shows a minimal, albeit not statistically significant, increase for the Prehab group that completed all their SF-12 surveys (n=205). As such, this lack of significant trend is similar to a recent study of older adults undergoing various types of elective surgery that reported no significant changes in depressive symptom burden from pre-surgery to 18 months post surgery (Cenzer et al., 2024). A previous study within cardiac surgery that utilized the SF-36 (a longer version of the survey from which the SF-12 was derived from (Ware et al., 1996) to measure mental health status showed a slight increase from pre-surgery to discharge, and then a statistically significant decline from hospital to six months post discharge leading to lower MCS-12 scores at study endpoint than at the start point (Elliott et al., 2006). In this study, the authors suggested that there might have been a result of patient expectations not being met post-recovery. In the present study, the study population mean 3-month post-discharge MCS-12 was relatively high at 54.72 ± 8.50; a recent study where the SF-12 was answered at the 3-month post discharge reported a mean MCS-12 of 47.87 ± 10 for 217 cardiac surgery patients (Nowicka-Sauer et al., 2023). Moreover, normative data for adults aged between 65 and 74 (the present study population mean age is within this band) indicates that the mean PCS-12 is 52.10 ± 9.53 for the general U.S. population (Ware et al., 1995). As such, the author believes that the higher than norm means of the study population may indicate that there is not much more improvement in quality of life with respect to mental health that could have met patient expectations. Assumably, patient expectations were quite high in general owing to their apparent higher starting mental health status than those of the general population. Nevertheless, this would need to be studied in greater detail that is out of the scope of the present study. It is also possible that the group who completed 1 year showed this trend, but in the future when the sample size is increased (i.e., more people complete the entire patient journey) this trend might become more apparent. Regardless, what is more apparent within this study is that CABG surgery appears to play a greater role in influencing patient reported physical health status rather than mental health status; the reasons for this discrepancy are unclear, and a potential explanation could relate to the fact that starting mental health status appears to be relatively higher than expected for this population.

6.3.6 Differences in SF-12 scores for flagged and not flagged Prehab patients

By examining the differences in SF-12 score trends between flagged (n=331) and not flagged Prehab patients (n=129), we can gain a better understanding of differences, if any, these patients experience from the start of their journey with the IVR system via enrollment in the Prehab AFU program till 1 year after discharge from hospital following CABG surgery.

With respect to median PCS-12 score, there was a slight, albeit statistically insignificant, difference between the flagged (n=331) and not flagged group (n=129) at the pre-surgery timepoint. However, this difference was statistically significant ($p<0.001$) between the two groups 3 months after discharge. Within groups, both groups had statistically significant ($p<0.001$) increases in median PCS-12 score between the two timepoints. As such, increases in PCS-12 score for the flagged group could be attributed to the combination of CABG and Prehab interventions, whereas the increase in PCS-12 score for the not flagged group could be attributed to CABG surgery alone. However, the magnitude of increase in PCS-12 differs between the groups as well. The not flagged group median score increased by 25%, compared to the flagged group which had an increase of 17.50% between the 1st day post Prehab AFU enrollment and three months post-discharge timepoints. When analyzing the change scores further, it was demonstrated that the difference in PCS-12 change scores was not statistically significant between the groups. Carrying this analysis further with the patients from the flagged and not flagged group who completed calls at 6 months and 1 year revealed a similar trend whereby PCS-12 change scores did not differ between groups. As such, there might be another unknown mechanism by which these differences are occurring; possible theories are presented later in this section.

In terms of median MCS-12 score, there was a statistically significant ($p<0.01$) difference between the flagged and not flagged group between the 1st day post Prehab AFU enrollment and three months post-discharge timepoints whereby the not flagged patients had a higher MCS-12 score. At three months post-discharge, the not flagged group still had a higher median PCS-12 score but the difference was statistically insignificant. Within groups, small but statistically insignificant differences were noted between the two timepoints. Extending this analysis further, there were no statistically significant differences in MCS-12 change scores between the groups at 3, 6 months and 1-year post-discharge. As such, the gap between the groups in terms of MCS-12 narrowed between the timepoints.

An explanation for the trends seen within these patients could be related to preoperative expectations that patients had prior to surgery playing an outsized role in their post-operative quality of life three months after discharge. A recent systematic review indicated that preoperative quality of life is an independent predictor for quality of life after surgery (Sanders et al., 2022). A couple of smaller studies have indicated that having higher preoperative quality of life (as measured by MCS via SF-36) might lead to no improvement or worsening of post-operative quality of life (Kurfirst et al., 2014; Norkienė et al., 2018). As such, this might explain the lack of trend in terms of improvement in MCS score for flagged patients as well as Prehab patients seen in the present study. However, a different trend is seen with the PCS-12 over time. It appears that having a higher PCS12 prior to surgery leads to PCS-12 increasing by a higher percentage change post-discharge compared to lower scoring PCS-12 patients. When breaking down the flagged group of patients by their number of flags (see section 8.4.3), this percentage change spread is consistent when comparing the not flagged group median PCS12 rate of change (25%, n=129) to the group with one flag (18.39%, n=195), the group with two flags (16.01%, n=101) and the group with three flags (13%, n=27); the trend is not consistent for the group with four flags (27.13%, n=8) but the small sample size decreases confidence that this last group can be reasonably used in comparisons. This difference in percentage change of PCS-12 follows the trend in pre-surgery median PCS-12 for these groups of 38.84 (not flagged), 37.79 (one flag), 35.23 (two flags), and 35.00 (three flags). Therefore, there seems to be an inherent difference in how PCS and MCS-12 change over timepoints. A recent study in cancer surgery patients indicated a similar finding where physical health expectations prior to surgery moderately correlated with actual physical health (reported via SF36) six months post-surgery, but mental health did not follow a similar trend (Panda et al., 2021). The authors suggested that these differences might be attributed to the approach of surgeons whereby physical health expectations are discussed and communicated more often than psychological expectations (Panda et al., 2021). In addition, the author of the present study believes that the inherent differences between the more objective questions assessing physical health in comparison to the more subjective questions on mental health within the SF-12 might also be playing a role in these divergent scoring trends. Patients might find it easier to see the impacts of Prehab and CABG on their physical health than how their mental health changed throughout the process. Another explanation for the trends seen in the PCS-12 scoring where the gap between flagged and not flagged patients is seen at 3- and 6-months post-discharge, but not at 1-year, could relate to the natural course of recovery from the surgery. As mentioned earlier, the recovery process from CABG surgery occurs over several months and hypothetically there is a plateau whereby no further improvements are possible. Therefore, it is possible that the closing of the gap is natural as perhaps the flagged patients lag the not flagged patients early in their recovery, but over the course of time their scores move towards those of their not flagged peers. These hypothetical explanations would need further study to gain a better understanding of these differences in scoring.

6.3.7 SF-12 score differences between Prehab and non-Prehab patients after surgery

As mentioned earlier, no statistically significant differences were observed at 3 months post-discharge. At 6 months and 1-year post-discharge, median PCS-12 score was approximately 3 points higher for Prehab patients than their non-Prehab counterparts. Moreover, slight differences in the percentage increase in median PCS-12 score from 3 months to 1-year post-discharge was seen between the groups; Prehab patients improved by 12.5% compared to 11.8% for the non-Prehab. Taken together, this suggests differences in physical HRQOL trajectory after surgery between these groups; Prehab patients' improvement is slightly better than non-Prehab patients with respect to physical HRQOL post-surgery. However, it is important to note that the lack of trend at 3 months post-discharge could be a sign that these differences seen later at 6 months and 1-year post-discharge could be a byproduct of smaller sample sizes. As sample size decreases, it is likely from a probabilistic perspective that the sample mean is moving further away from the actual population mean as is explained in the central limit theorem. Theoretically, what was observed here for median could be highlighting a similar phenomenon to the central limit theorem explanation for decreases in confidence with smaller sample sizes for mean.

6.3.8 Further exploring associations between potential predictor variables and study outcomes via regression analysis

6.3.8.1 Associations between potential predictor variables and study outcomes for the study population

Regression analysis was conducted in the study to assist with elucidating the relationship between potential predictor variables and outcome variables (PLOS, readmission, STS operative mortality, and SF-12 where appropriate). At first, regression analysis was conducted for the study population (N=2185) to give an overview of the most common predictors for CABG patients; these are summarized in the results section above. Overall, findings were in line with previously established associations for most of the significant predictor variables included in models. Demographic variables such as older age (O'Brien et al., 2018) or female sex (Gaudino et al., 2023) are known to be associated with worse post-operative outcomes. Risk factors such as renal failure or heart failure are also known to contribute to poorer post-surgery outcomes (O'Brien et al., 2018). Perioperative/surgical factors such as undergoing combined Mitral Valve Repair (MVR) and CABG (Ullah et al., 2022) or Aortic Valve Repair (AVR) and CABG (Canadian Institute for Health Information, 2022) are more complex than isolated CABG and can sometimes lead to poorer outcomes. Post-surgery complications such as infections (Zukowska & Zukowski, 2022) or major morbidity events as per the STS definition have been established to worsen outcomes; for the latter, outcomes worsen increasingly correspondent to increasing number of events (Seese et al., 2020). As such, the modelling for PLOS and readmission is in line with previously established predictor variables and their associations with these outcomes. The modelling for operative mortality is in line with previous research, except for the unexpected finding of having one diseased vessel (compared to not having one diseased vessel) contributing to an increase in the odds of mortality occurring. This is contradictory to previous research that indicates having three diseased vessels to be more predictive of higher operative mortality risk than one or two diseased vessels (Lopes et al., 2008). There are a couple of possibilities to explain why this finding occurred. Firstly, the one diseased vessel in this case could have been the left coronary artery. The left coronary artery is responsible for delivering about 50% of the blood supply to heart muscle. A blockage in the left main coronary artery or the proximal LAD, which is fed by the left main artery, can lead to narrowing of these arteries known as stenosis. Left main stenosis of greater than 50% or proximal LAD stenosis of greater than 70% can increase CABG surgical and outcomes risk as per the STS online risk score calculator (O'Brien et al., 2018). This is most likely a byproduct of overfitting occurring as a result of the low number of mortality events in comparison to the much larger number of predictor variables (Riley et al., 2019).

6.3.8.2 Associations between potential predictor variables and study outcomes for Prehab patients

The multivariable regression analysis specifically for Prehab patients enabled the examination of the associations between SF-12 scores and PLOS or readmission. However, the model selection process utilized in this study indicated that when controlling for the wide range of demographic variables, risk factors, surgical factors and so on, there were more significant predictor variables for these outcome variables than either PCS or MCS-12. When attempting to force PCS-12 (owing to bivariate level significance in the relationship between PCS-12 and PLOS) into PLOS models presented earlier, there was an overall poorer model fit noted and the directionality of the relationship reversed to indicate increasing PLOS with increasing PCS-12 score. Despite this, the PCS-12 measure in this study did appear to closely resemble the improvements in physical health for patients as evidenced by the encouraging trends in post-operative outcomes. To extend this analysis, the Prehab group was further studied at 3,6 months and 1-year post-discharge to elucidate predictive factors that impacted SF-12 scores at these timepoints.

6.3.8.3 Associations between potential predictor variables and SF-12 scores for Prehab patients

Overall, there were some trends that appeared through the modelling at 3 months as seen earlier in the results section. For both MCS-12 and PCS-12, the binary predictor of being flagged (vs. not being flagged) was estimated to be a risk factor leading to lower score at this timepoint. However, as seen earlier, the effect of being flagged or not flagged is dependent on context. The apparent significance in these regression models does not seem to translate to a meaningful independent effect after accounting for baseline scores, as previously implied by the non-parametric ANCOVA. The other predictors are reasonable, with variables such as heart failure, smoking everyday and post-operative infection leading to worse PCS-12 scores at 3 months. However, MCS-12 modelling was not as straightforward as PCS-12 modelling. In this case, post-operative infection was modelled to be a protective factor, leading to a higher MCS-12 score. This may have occurred due to closer MCS-12 scores at this time which showed no statistically significant difference between groups at this time; this contrasts with the PCS-12 scores which were statistically significantly different at this time. At 6 months post-discharge, no common predictor variables were shared between the PCS-12 and MCS-12 models. The MCS-12 model predictors of having two flags and having a readmission being associated with a lower MCS-12 score at 6 months are reasonable. However, having the surgery scheduled as an elective surgery (i.e., not an urgent/emergency case) leading to lower MCS-12 score is a surprising result. From a logical perspective, one would not assume that the lack of urgency of a surgery would negatively impact scores; if anything, the opposite where urgent cases could score lower could be expected. As such, this finding needs to be interpreted with caution. In terms of PCS-12 at 6 months, the predictors selected appeared to be reasonable. Interestingly, being female was also selected as a risk factor here, as well as at 3 months with respect to having a lower PCS-12 score. At 1 year after discharge, there was only one variable selected as a protective factor for having a higher MCS-12 score. However, this is at odds with what is known in the literature. Generally, patients with three diseased vessels are at higher risk of morbidity and mortality than single or two disease vessel patients (Lopes et al., 2008). Presumably, this would translate to a lower MCS-12 score, but in this case, it appears to represent the opposite. Regarding PCS-12, the modelling results were mixed. Having three flags (vs. not being in that category) was selected as a risk factor, but having four flags was seen as a protective factor. The other risk factors, hypertension and class III heart failure are reasonable, as is the protective factor of never having been a smoker which have been seen in previous literature to be independent predictors of HRQOL after cardiac surgery (Sanders et al., 2022). Overall, most predictors selected for at 3,6 months and 1-year post-discharge to be significantly associated with PCS-12 or MCS-12 score are reasonable, except for those mentioned earlier in this section. However, the picture of association between flagged/not-flagged and PCS/MCS-12 is not entirely clear. Owing to the conflict between the regression analysis and the non-parametric ANCOVA presented earlier, this result highlights the impact of baseline scores. As such, baseline scores in this study appear to function as a confounder. Their significance in regression analysis potentially reflects an indirect association between the variables of being flagged/flagged and post-discharge SF-12 scores that is mediated by baseline differences rather than a direct effect. The non-parametric ANCOVA analysis may therefore serve to reduce this 'noise' to provide a clearer view of true associations at these timepoints. However, regression analysis still has merit in this sense as the models depict total effects of predictors including the flagged/not-flagged predictor.

However, since the Prehab group overall were in better health than their non-Prehab counterparts, a further regression analysis was conducted with only non-Prehab patients to enable deeper analysis of the most predictive factors for CABG patients that did not enroll into the AFU program prior to surgery.

6.3.8.4 Associations between potential predictor variables and study outcomes for non-Prehab patients

As the potential confounding influence of Prehab patients is removed from the regression analysis for the non-Prehab group, these are more indicative of what could be expected to be the most predictive factors for CABG patients who do not enroll in the Prehab AFU program before surgery. As such, these models include slightly lesser predictor variables than those for the overall population which aids in simplification. For instance, the case of major morbidity is cleared up; having no major events is the largest protective factor and having three major events is the largest risk factor for PLOS. Moreover, there are notable differences between the readmission and PLOS models for the non-Prehab group compared to the Prehab group.

6.3.8.5 Associations between potential predictor variables and study outcomes for flagged and not flagged patients

Regression analysis was attempted to explore potential predictor variables for PLOS and readmission for flagged patients and not flagged patients (both part of the Prehab group), but poor modelling was seen. This was most likely due to the small numbers of outcomes occurring (small number of readmissions), limited variation in PLOS, and small sample sizes for these groups.

6.4 Prehab AFU Program Evaluation Summary Via FDECI framework

With respect to the FDECI framework, the research objectives and subsequent analysis in this project were aimed at gaining more information on the effectiveness and theory based domains of the Prehab AFU program. These domains are presented here in the following table, along with explanations of applicable findings.

Table 29. Relevant FDECI framework research questions and key takeaways. Adapted from (Skivington et al., 2021).

Research Perspective/Question	Main Takeaways from Study
Effectiveness	
To what degree does the intervention produce desired outcomes in non-experimental/clinical settings?	• Overall effectiveness seen via differences in study outcomes favouring Prehab patients over non-Prehab patients. • Flagged patients' ability to recover in comparable manner to not flagged patients hints at effectiveness of Prehab program at closing health status gaps between these patients (as seen via ranked SF-12 change score comparisons).

Theory Based	
What (about the intervention) functions in which conditions and how does it do so?	• Quite likely pre-surgery interventions improve patient health status prior to surgery, which leads to improved post-surgery outcomes. • IVR system engagement might be acting as safety net, as seen in Prehab vs. non-Prehab IVR engagement rate. • A key concern is why flagged patients cannot close PCS-12 gap with not flagged patients over time despite similar change scores. Could patient expectations play a role here, or is there another reason for this?

The following paragraphs expand on the information presented in the table above. Initial evidence of effectiveness was provided in a recent cohort comparison of patients prior to and post implementation of the program (Charlebois et al., 2023). The present study was guided by this work to select the most pertinent research questions to better understand how the program is being used in its current setting as well as where potential improvements could be made to then improve the effectiveness of the intervention. One such example of improving effectiveness relates to the apparent difference whereby those with poorer self-rated physical health prior to surgery improve post-surgery but at a lesser rate than their higher self-rated peers By exploring the role, if any, patient expectations could be playing prior to surgery on post-surgery self-rated physical health via a patient expectations survey at the first timepoint of the Prehab AFU program, there might be a way in which to close this gap in self-rated physical health post-discharge. A short survey such as that utilized by Panda and colleagues could be added to the IVR algorithm if not found to be overly burdensome (Panda et al., 2021). This would theoretically then feed back into the overall effectiveness of the Prehab AFU program by enabling consistent gains for all regardless of starting point health wise.

There are a few theoretical considerations that might help explain how the intervention is producing outcomes for Prehab patients. Specifically, these revolve around trying to identify uncertainties as described in the FDECI framework. It is quite likely that the interventions done prior to surgery help improve patient health status prior to surgery, which makes them more resilient to the challenges of surgery and the associated recovery period. From the perspective of the IVR system itself, it might be suggested that the adherence of Prehab patients to continuing to engage with the IVR system post-surgery may play a role in acting as a safety net for these patients. From a probabilistic point of view, engaging with the system (as Prehab patients did at a higher rate than non-Prehab patients did post-discharge) is more likely to flag a potential issue earlier than if there is no engagement whatsoever. In the non-engagement scenario, patients might seek medical advice at a later stage once symptoms worsen. In terms of how potential differences in outcomes might be occurring within patients in the program, the difference between patients who were not flagged and those that were flagged provides some indication of an underlying pre-surgery difference between these patients. As shown earlier, these patients are overwhelmingly similar in terms of starting health status as seen via demographic or risk factors. Moreover, they are also similar in terms of SF-12 change scores from pre-surgery till any of the 3, 6 months or 1-year discharge timepoints. Since the SF-12 is a reliable HRQOL indicator, by proxy, the difference in PCS-12 scoring may be reflecting a non-physical factor (as these patients are similar in traditional clinical indicators of physical health prior to and post-surgery) that is impacting self-rated physical health status after program enrollment (as median PCS-12 scores are non-significantly different at the first timepoint) till at least three months post-discharge. Although these differences are not realized in the traditional post-surgery outcomes, they are being borne out within the domain of HRQOL. Since it has been established that poor HRQOL can identify patients who are at risk of worse long term survival outcomes (Koch et al., 2007), it would be pertinent to seek out ways in which to improve HRQOL for all patients throughout their patient journey. In this scenario, it is particularly important to focus on increasing SF-12 scores (by way of improving health status) prior to surgery, as baseline scores were seen to have a statistically significant effect on post-surgery scores.

6.5 Synthesis of key findings in relation to study objectives

This table summarizes the research questions of the present study and includes how the answers to these questions were elucidated as well as conclusions to draw from doing so.

Table 30. Summary of research findings and conclusions.

Research Questions	Method of Elucidating Answer & Conclusion
Are there differences in IVR system utilization across distinct subgroups of CABG patients?	• Examined overall trends in IVR utilization. • Analyzed within and between group differences for Prehab vs. non-Prehab group. **Conclusions**: • Prehab group engages with IVR at higher rates than non-Prehab. • Opportunity to increase engagement of non-Prehab patients with IVR system post-discharge to decrease no contact calls and associated time burden. • Within Prehab group, flagged and not-flagged patients are quite similar with respect to IVR system engagement prior to and post-surgery.
Are there changes and differences in CABG patients' process of care and outcomes associated with the IVR technology use in the Prehab AFU program?	• Examined within and between differences in outcomes (PLOS, readmission, STS operative mortality, SF-12) for all patients, followed by differences between key groups such as Prehab vs. non-Prehab, flagged vs. not flagged. • Further analyzed abovementioned differences by regression analysis. **Conclusions**: • Similar improvements to care seen as previously published recent study at UOHI. • Key differences seen for Prehab vs. non-Prehab patients in PLOS, STS operative mortality, post-discharge SF-12 • Pre-surgery PCS-12 inversely associated with PLOS for Prehab patients.
Are there differences in outcomes of care among CABG patients when comparing across distinct subgroups or between CABG patients who	• Examined within and between groups differences for flagged vs. not flagged patients (flagged patients required intervention post-IVR screening) with respect to study outcomes.

require intervention post-IVR screening as opposed to their counterparts?	• Explored differences further via regression analysis and non-parametric covariance analysis. **Conclusions**: • No post-operative differences in PLOS and readmission outcomes seen between flagged and not flagged patients. • Differences seen within SF-12 scores before and after CABG surgery. Generally. flagged patients scored lower but ranked change scores analysis via covariance analysis indicated baseline scores influenced these lower post-surgery scores more than being flagged vs. not flagged. • No evidence to indicate that increasing need for intervention (seen via proxy measure of number of flags raised during IVR screening) influenced study outcomes. Thus, not enough evidence to suggest that the initial hypothesis whereby those with more flags would have worse study outcomes could be likely.

The methods by which the research objectives were met are detailed below. These provide greater and more specific details that build upon the information presented in the table above. The first research objective, an expansion on the first and second research question above, is outlined here:

Evaluate the impacts of the IVR technology in the Prehab AFU program on the process of care for CABG patients by analyzing the pattern of utilization of Prehab interventions over time and the adjustments made in the process in preparation for surgery.

This was met by exploring the overall trends in IVR utilization as well as differences between Prehab patients (within group) and non-Prehab (between groups); almost 50% of calls were being completed without manual intervention by the clinical team and did not raise health concerns. However, the considerable amount of no contact calls presents an opportunity to further emphasize to patients the importance of engaging with the IVR system, especially for non-Prehab patients as they appear to engage with the IVR system at different rates than their Prehab counterparts. In the Prehab group, few differences were seen after comparison between flagged and not flagged patients. This indicates that Prehab patients overall have similar usage of the IVR system.

The second research objective, which builds upon the second and third research questions, is outlined here:

Assessing the changes in patients' health status/HRQOL (SF-12) pre and post surgery and examining the association between the SF-12 score changes and the number of calls received by patients.

This was met by exploring SF-12 score differences between groups (Prehab vs. non-Prehab) and within groups (flagged vs not flagged), including bivariate analysis where higher PCS-12 was found to be associated with lower PLOS for Prehab patients.

The third research objective, which further builds on the third research question, is shown here:

Assessing differences in CABG patients' outcomes between different subgroups of patients by differences, if any, in study outcome measures (i.e., readmission, STS operative mortality, PLOS, and SF-12 where appropriate).

This objective was met by exploring within and between group differences in patients. Further analyzed via regression analysis for predictive factors for these outcomes within larger subgroups, including Prehab vs. non-Prehab, and flagged vs. not flagged.

The final research objective, which expands on a combination of all three research questions, is outlined below:

Examine the differences in outcomes between CABG patients who require interventions after screening stage of IVR Prehab when comparing to their counterparts who do not require interventions post-screening, as well as comparing between patients by number of Prehab interventions signaled by responses to the IVR system.

This was met by examining differences between Prehab patients (flagged vs. not flagged) and between flagged patients (1,2,3, and 4 flags groups). No differences in post-operative outcomes were noted between Prehab patients but increasing HRQOL differences (via SF-12) were seen between pre-surgery and 3 months post-discharge for flagged patients compared to not-flagged patients. Further analysis of ranked change scores via non-parametric ANCOVA revealed that ranked scores did not differ in a statistically significant manner between flagged and not flagged patients at 3 months post-discharge. Furthermore, the flagged/not flagged designation was not seen to have a statistically significant effect on ranked change scores at 3 months post-discharge. Instead, baseline SF-12 scores were observed to have a statistically significant effect on ranked change scores. This analysis was expanded on further by including groups of patients who had completed 6 months post-discharge, and patients who had completed their entire journey up to 1-year post-discharge. Differences were seen in median PCS-12 and MCS-12 where not flagged patients had higher median scores at 6 months, and not flagged patients had higher median MCS-12 at 1 year. However, ranked change score analysis for flagged and not flagged patients compared at 6 months or at 1 year did not reveal any statistically significant differences. This again indicates that the flagged/not flagged variable does not appear to impact on ranked change scores and that baseline SF-12 scores do have a statistically significant effect on ranked change scores for flagged and not flagged patients at 6 months and 1-year post-discharge. However, it is pertinent to note that these findings are based on relatively small groups of patients. For instance, there were 240 flagged and 93 not flagged patients that were compared in terms of ranked change scores from pre-surgery to 6 months post-discharge. Also, 175 flagged patients were compared to 60 not flagged patients for ranked change score differences from pre-surgery to 1-year post-discharge. Therefore, it is not out of the realm of possibility that this analysis reveals different trends once larger groups of patients go through the program and there is less likely to be effects of sampling error similar to those seen in survival bias occurring. Nevertheless, this finding further illustrates the importance of and impact that pre-surgery SF-12 scores have on post-surgery SF-12 scores in this study. This finding also corroborates previous findings with respect to pre-operative quality of life being an independent predictor of quality of life post-discharge (Sanders et al., 2022). With regards to the previously stated hypothesis of more pre-surgery flags being associated with worse outcomes, no statistically significant differences in post-operative outcomes and SF-12 were observed in the flagged patients. Despite decreasing PCS-12 scores from the 1 flag to the 3 flags group, this lack of differences suggests that raising more flags is not associated with worse SF-12 score or post-operative outcomes as was hypothesized earlier.

7 Limitations

As with all research that is conducted, especially in real world settings, there are several potential limitations that must be kept in mind. Firstly, this study utilizes data that has been collected through routine clinical processes. As such, there is no blinding of clinical staff or patients as there is within an experimental study. Secondly, as there is no control group for the use of IVR during Prehab (i.e., a group of patients that undergo Prehab without IVR), it is difficult to examine the direct effectiveness of the intervention. However, previous work by Charlebois and colleagues (Charlebois et al., 2023) helps to provide clarification in this area whereby a pre and post IVR implementation cohort comparison study indicated positive benefits for CABG patients post IVR implementation. Thirdly, the timepoints in which the SF-12 is delivered can act as a limitation to the study. As the SF-12 is delivered once before surgery (i.e., upon enrollment in the Prehab program) and is not conducted again until after the CABG procedure is completed, it is difficult to separate the impacts, if any, of the CABG surgery on SF-12 scores from the impacts, if any, that the Prehab program had on SF-12 scores for patients. As such, it is more difficult to suggest that the changes before and after surgery in SF-12 scores, if any, result solely from IVR implementation within the Prehab AFU program. Another possible limitation is the single centre nature of the study that may impact the generalizability of the findings from this result. However, the study population is most probably heterogeneous owing to the country wide referrals of patients from across Canada to the UOHI for CABG; this helps to mitigate the single centre nature of the study by including a diverse range of patients. A limitation inherent to the clinical focus of the Prehab AFU program is that the question algorithm for the Prehab AFU IVR system has been modified throughout the duration of the study. As such, some of the questions may have been overtly sensitive and may have picked up more noise than would have happened after the change in the algorithm. For instance, the algorithm for flagging a person at risk of nutritional deficiency (and thus requiring a nutritional screen with a nutritional professional) was modified so that negative responses to 2 questions would raise a flag for the system; the requirement for a flag was 1 negative response to 2 questions before this change. Lastly, there are also some inherent limitations with respect to the SF-12 questions. The questions were scored using a previously established and publicly available manual that was designed by the creators of the SF-12 survey for version 1 (Ware et al., 1995); the SF-12 version used in the Prehab AFU IVR system differs by one response level to the social functioning question that is a constituent of the MCS-12 scale. As such, the scoring of the MCS-12 for 130 patients in the cohort may not be accurate; those who answered, “a little of the time” and “none of the time” were both scored at the same level. However, the accurate scoring of the rest of the MCS-12 constituents aids in negating the potential impact of this inaccuracy. Another limitation of the study comes from inherent limitations with the chosen modelling approach. As a consequence of having an inclusion requirement for predictor variables of surpassing the $p<0.05$ threshold at the bivariate level, there is a possibility that some potentially predictive predictor variables were dropped too soon from the modelling approach (Grant et al., 2019). However, this is negated as the models (except for the models for the collective study population) are generally stable with low variance inflation factor (VIF) values and most predictor variables included in final models closely resemble previous literature on predictive variables for the outcome measures within the study. The author believes the instability for the models for the study population arises due to the post-surgery morbidity burden being lower (i.e., 0,1, or 2) for Prehab patients than it was for non-Prehab patients, as the models for non-Prehab patients alone (i.e., Prehab patients removed) were generally stable as evidenced by low VIF values (see Appendix).

8 Implications

The main implications from this study can be broadly categorized into one of three categories: implications for the clinical team/unit, implications for stakeholders outside of the team, and research implications.

With respect to the clinical team, there are a few considerations that could factor in the future. The findings from this study suggest that the SF-12 can play a role in predicting patient outcomes. Within this study, a higher PCS-12 score was associated with a lower PLOS for all Prehab AFU program patients at a bivariate level; this suggests that the team may want to include this information alongside other critical clinical information within resource allocation. For instance, planning with respect to the allocation of beds post-surgery could consider poorer PCS-12 scores as being indicative of requiring longer stays and thus be included in forecasting of bed allocations. Another recommendation would be to examine the possibility of increasing patient education on the importance of engaging with the IVR system. As mentioned previously, the considerable number of no contact calls especially for non-Prehab patients represents greater resource strain for the team. If more awareness was raised among these patients for the importance of responding promptly and accurately to the IVR system calls, the number of no contact calls for this group might decrease and thus continue to reduce resource strain on the clinical team. Another area of exploration could be related to patient expectations. As mentioned earlier, patient expectations might be important to consider prior to surgery. The clinical team might investigate the possibility of adding a brief survey that seeks patient views on the expectations for their surgery and subsequential recovery. Alternatively, patient expectations could be assessed at some time around the surgical consultation with the cardiac surgeon prior to enrollment into the Prehab AFU program. Then, this could allow the team to observe impacts, if any, that patient expectations have on patient recovery.

Outside of the clinical team, there are implications for those within healthcare. For instance, healthcare organizations around the world can use lessons learned by the clinical team (and the healthcare organization where the team is located i.e., the UOHI). This includes lessons learned at the UOHI in the successful implementation of an automated IVR system that could be used both to assist with pre-surgery screening (Charlebois et al., 2023), chronic condition monitoring (Sherrard et al., 2015; Woodend et al., 2008), and post-surgical monitoring (Sherrard et al., 2009). Moreover, this study highlights the potential for using established health surveys such as the SF-12 to aid clinicians in gaining further insight into the physical and mental health status of a patient. This information could then be utilized by clinicians in various stages of the care journey for cardiac surgery patients, such as prior to surgery or post-surgery resource allocation.

With respect to research implications, there are a couple of paradigms that could be expanded. As seen in this study, HRQOL differences can exist even when traditional clinical outcomes do not differ as was seen between flagged and not flagged Prehab patients. Further exploration of why these differences occurs, if they occur, within other homogenous groups of patients in cardiac surgery could be one such avenue of research. Similarly, research into this apparent disparity of pre-operative HRQOL not matching the similarity of short-term post-operative outcomes for an almost homogenous group of cardiac surgery patients could be examined as well in a similar vein.

9 Future Directions

There are several directions in which this research can be further built upon in the future. Firstly, the author believes that the current research can be utilized in building predictive models in the future for the Prehab AFU program. Essentially, collected data from a future cohort would be run through descriptive statistics and bivariate level analysis. Then, using a combination of clinical knowledge from team members and findings from this study, predictive models could be developed to assist team members with identification of patients with higher expected resource use. The development of the model could include a data splitting approach with approximately 80% of the collected data used in training a model and 20% to test model performance to guard against overfitting (Joseph, 2022). Secondly, other researchers might be able to expand on this work further by carrying the analysis all the way through the patient journey in the Prehab AFU program prior to surgery. Namely, the flags generated by the IVR system at the call shortly after program enrollment was used as a proxy for undergoing that intervention for which the flag was raised. However, this may not be entirely accurate as patients may have incorrectly responded to the question, not understood the question and so forth. As such, it is likely that not all patients who raised flags underwent interventions prior to surgery or could have undergone more, or less interventions, than the number of flags that they raised.

10 Conclusion

In summation, the Prehab AFU program is a complex intervention that incorporates several areas of previous research findings such as prehabilitation or digital health technology to provide care for patients throughout their CABG surgery journey at the UOHI. The present study utilized a complex intervention research lens to evaluate the program especially in the realm of key uncertainties. Namely, better understanding the differences, if any, in the effectiveness of the program for different types of patients as well as asking theory based questions that delve deeper into understanding how and why the program produces positive results for patients. Results highlighted some areas of difference with respect to engaging with the system between patients who enroll in the program prior to surgery and those who are enrolled post-discharge. Moreover, pre-post-surgery differences in self-rated HRQOL between subsets of Prehab patients were noted as well, hinting at the possibility of otherwise similarly healthy patients having different experiences within the patient journey. When examining these results in a broad manner, it suggests that CABG patients have different experiences with the program. For instance, the considerable proportion of non-Prehab patients not engaging with the IVR system post-surgery suggests that these patients may not have as much awareness regarding the importance of doing so. This contrasts with Prehab patients of which the majority are engaging with the system. Although a few possible explanations were presented earlier for this discrepancy, this would need to be further explored in the future to transfer the positive impacts of the program (which are positive for most patients) seen within traditional clinical indicators to assist in improving how patients perceive their experience via self-rated HRQOL. As such, this study provides decision making stakeholders of the Prehab AFU program with valuable insight into how the program may be producing the desired positive effects. Future research to better understand if patient expectations play a role in modulating these positive effects for self-rated HRQOL may prove useful. By doing so, equitable improvements for all patients within the program may be achieved for self-rated HRQOL.

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Appendix

Performance Metrics for Models

Study Population PLOS

Low Correlation

Term	VIF	VIF 95% CI	Increased SE	Tolerance	Tolerance 95% CI
Age	1.04	[1.01, 1.13]	1.02	0.96	[0.88, 0.99]
BMI	1.04	[1.02, 1.13]	1.02	0.96	[0.88, 0.98]
DumFemale	1.01	[1.00, 5.18]	1.00	0.99	[0.19, 1.00]
DumRenalFailure	1.02	[1.00, 1.23]	1.01	0.98	[0.81, 1.00]
DumPriorMI	1.03	[1.01, 1.15]	1.01	0.97	[0.87, 0.99]
DumHeartFailure	1.07	[1.04, 1.14]	1.04	0.93	[0.87, 0.97]
DumReadmissionICU	1.06	[1.03, 1.14]	1.03	0.94	[0.88, 0.97]
DumMorbidity2	4.53	[4.20, 4.91]	2.13	0.22	[0.20, 0.24]
DumProcedureCatCAB	2.75	[2.56, 2.96]	1.66	0.36	[0.34, 0.39]
DumProcedureCatOther	2.67	[2.49, 2.88]	1.64	0.37	[0.35, 0.40]

High Correlation

Term	VIF	VIF 95% CI	Increased SE	Tolerance	Tolerance 95% CI
DumMorbidity0	18.71	[17.18, 20.38]	4.33	0.05	[0.05, 0.06]
DumMorbidity1	15.34	[14.10, 16.70]	3.92	0.07	[0.06, 0.07]

Study Population Readmission

Low Correlation

Term	VIF	VIF 95% CI	Increased SE	Tolerance	Tolerance 95% CI
DumRenalFailure	1.00	[1.00, 6159.83]	1.00	1.00	[0.00, 1.00]
DumIMAused	1.01	[1.00, 1.70]	1.01	0.99	[0.59, 1.00]
DumPostopInfectionboth	1.03	[1.01, 1.14]	1.01	0.97	[0.88, 0.99]
DumPostopInfectious	1.06	[1.03, 1.13]	1.03	0.95	[0.88, 0.97]
DumMorbidity1	1.05	[1.02, 1.13]	1.02	0.96	[0.89, 0.98]

Study Population STS Operative Mortality

Low Correlation

Term	VIF	VIF 95% CI	Increased SE	Tolerance	Tolerance 95% CI
DumRenalFailure	1.09	[1.05, 1.16]	1.04	0.92	[0.86, 0.95]
DumDiseasedVesselsOne	1.07	[1.04, 1.14]	1.04	0.93	[0.88, 0.96]
DumSecondCardiacSurgReop	1.05	[1.02, 1.13]	1.02	0.95	[0.89, 0.98]
DumMorbidity3	1.03	[1.01, 1.13]	1.02	0.97	[0.88, 0.99]

Prehab Patients PLOS

Low Correlation

Term	VIF	VIF 95% CI	Increased SE	Tolerance	Tolerance 95% CI
Age	1.07	[1.01, 1.54]	1.03	0.94	[0.65, 0.99]
BMI	1.14	[1.04, 1.44]	1.07	0.88	[0.69, 0.96]
DumFemale	1.05	[1.00, 1.89]	1.02	0.96	[0.53, 1.00]
DumHeartFailure	1.12	[1.04, 1.44]	1.06	0.89	[0.70, 0.97]
DumGrafts4	1.06	[1.01, 1.62]	1.03	0.94	[0.62, 0.99]
DumMorbidity2	1.07	[1.01, 1.52]	1.04	0.93	[0.66, 0.99]
DumMorbidity3	1.08	[1.01, 1.49]	1.04	0.93	[0.67, 0.99]
DumProcedureCatAVRCAB	1.08	[1.01, 1.49]	1.04	0.93	[0.67, 0.99]
BypassTime	1.15	[1.05, 1.45]	1.07	0.87	[0.69, 0.95]

Prehab Patients Readmission

Low Correlation

Term	VIF	VIF 95% CI	Increased SE	Tolerance	Tolerance 95% CI
DumSmokerFreqUnknown	1.02	[1.00, 4.08]	1.01	0.98	[0.24, 1.00]
DumPostopInfectionboth	1.05	[1.01, 1.35]	1.03	0.95	[0.74, 0.99]
DumPostopInfectious	1.05	[1.01, 1.35]	1.03	0.95	[0.74, 0.99]
DumMorbidity0	1.01	[1.00, 25.52]	1.01	0.99	[0.04, 1.00]

Non-Prehab Patients PLOS

```
Low Correlation

                   Term  VIF   VIF 95% CI Increased SE Tolerance Tolerance 95% CI
                    Age 1.01 [1.00, 5.41]         1.00      0.99     [0.18, 1.00]
       DumRenalFailure 1.01 [1.00, 2.06]         1.01      0.99     [0.49, 1.00]
       DumHeartFailure 1.05 [1.02, 1.16]         1.03      0.95     [0.86, 0.98]
     DumReadmissionICU 1.02 [1.00, 1.30]         1.01      0.98     [0.77, 1.00]
         DumMorbidity0 1.06 [1.02, 1.16]         1.03      0.95     [0.86, 0.98]
         DumMorbidity3 1.01 [1.00, 1.59]         1.01      0.99     [0.63, 1.00]
     DumProcedureCatCAB 2.44 [2.25, 2.66]         1.56      0.41     [0.38, 0.45]
   DumProcedureCatother 2.36 [2.18, 2.57]         1.54      0.42     [0.39, 0.46]
```

Non-Prehab Patients Readmission

```
Low Correlation

                     Term  VIF      VIF 95% CI Increased SE Tolerance Tolerance 95% CI
          DumRenalFailure 1.01 [1.00, 133.18]         1.00      0.99     [0.01, 1.00]
               DumIMAused 1.01 [1.00,   1.76]         1.01      0.99     [0.57, 1.00]
  DumPostopInfectionboth 1.01 [1.00,   1.56]         1.01      0.99     [0.64, 1.00]
     DumPostopInfectious 1.02 [1.00,   1.29]         1.01      0.98     [0.78, 1.00]
```

Non-Prehab Patients STS operative mortality

```
Low Correlation

                    Term  VIF   VIF 95% CI Increased SE Tolerance Tolerance 95% CI
         DumRenalFailure 1.11 [1.06, 1.19]         1.05      0.90     [0.84, 0.94]
  DumDiseasedVesselsone 1.19 [1.13, 1.28]         1.09      0.84     [0.78, 0.88]
             DumCABGMVST 1.12 [1.07, 1.21]         1.06      0.89     [0.83, 0.93]
```

Model of PCS-12 score at 3 months post-discharge being dependent variable (section 6.3.1)

	PCS-12		
Predictors	*Estimates*	*CI*	*p*
(Intercept)	45.84	45.08 – 46.60	**<0.001**
Female	-3.98	-5.34 – -2.61	**<0.001**
Diabetes	-1.80	-2.87 – -0.72	**0.001**

Renal Failure	-7.78	-13.08 – -2.49	**0.004**
Smoke everyday	-3.86	-5.36 – -2.36	**<0.001**
HFClassIII	-3.90	-5.75 – -2.05	**<0.001**
Readmission [Yes]	-6.36	-8.68 – -4.04	**<0.001**
Observations	1328		
R^2 / R^2 adjusted	0.090 / 0.085		