The Association Between Waiting Time and Starting, Completion and Outcomes in Post-Surgical Cardiac Rehabilitation Patients Following Sternotomy

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Abstract

Aim:
Prolonged waiting times for post-surgical cardiac rehabilitation (CR) patients following sternotomy may influence their chances of starting, completing, and potentially determine the extent by which patients benefit. This thesis examined the level of association between waiting time and CR utilisation and outcomes for patients following sternotomy.

Methods:
A critical literature review concluding in 2022 evaluated 26 eligible papers helping to identify important factors associated with CR timing and outcome. These factors also informed the National Audit of Cardiac Rehabilitation (NACR) database and subsequent analysis. The data collected by NACR between 2013 and 2019 were analysed using regression models in the following observational studies:

- Starting CR and waiting time study: assessed the association between CR starting and waiting time, patient and cardiac-event factors.
- CR completion and waiting time study: assessed the association between CR completion and waiting time, patient, cardiac-event, pre-CR assessment and CR delivery factors.
- CR outcomes and waiting time study: assessed the association between CR outcomes of cardiovascular risk factors, psychological health and physical fitness and waiting time, patients, cardiac events, and CR delivery factors.

Results:
There were 93,869 patients post-surgery with a mean age of 67 (SD = 11) years 25% of the population was female. The likelihood of post-surgical patients starting CR increased with waiting more than 6 weeks from the treatment compared to starting early and waiting up to 6 weeks by OR: 2.55. In contrast, for patients who waited more than 6 weeks to start CR, their probability of completing CR decreased by OR: 0.94. Waiting longer was negatively associated with physical activity status, depression, and physical fitness measures.

Conclusion:
This thesis is the first to conduct observational studies of routine practice clinical data in post-sternotomy patients' investigating waiting times and their association with CR starting, completion and outcomes. The thesis provides clinically relevant insight into waiting time and related factors that influence patients' chances of CR utilisation and the extent of benefit following rehabilitation. A key recommendation is that CR programmes and their patients will likely benefit from tailoring their services according to patient factors identified as influential in this work.

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Finally, to my wonderful mother and father, I dedicate this thesis to you.

Author's Declaration

I declare that this thesis is a presentation of original work, and I am the sole author. This work has not previously been presented for an award at this, or any other, University. All sources are acknowledged as references.

CHAPTER 1 Introduction and Literature Review

1.1 Introduction

Cardiovascular diseases (CVD) are a dominant cause of mortality globally (Gaziano et al., 2009; Gersh et al., 2010). They were found to be responsible for 4 million deaths in Europe and 170,000 deaths each year in the UK. Furthermore, according to the British Heart Foundation (BHF), there were 7.4 million people diagnosed with CVD in the UK in 2019 (British Heart Foundation, 2019a). The term "cardiovascular diseases" describes several disorders affecting the heart and blood circulation, such as coronary artery disease (CAD).

CAD is a decrease in myocardial blood flow due to the narrowing of the arteries by atherosclerotic plaques (Stone, 2012). Both coronary artery bypass grafting (CABG) and percutaneous coronary intervention (PCI) are used as approaches for coronary revascularisation for CAD patients. Several studies investigated the appropriateness of both treatment types and concluded that CABG is more beneficial for CAD patients in terms of a decreased incidence of repeat revascularisation and reduced mortality rates (Bravata et al., 2007; Deb et al., 2013; Spadaccio and Benedetto, 2018).

Although surgical procedure CABG increases myocardial perfusion by bypassing the narrowed coronary arteries using a grafted vessel via a sternotomy, all major guidelines, including the European Association of Cardiovascular Prevention and Rehabilitation, the American Association of Cardiovascular and Pulmonary Rehabilitation (with the American College of Cardiology Foundation and the American Heart Association) and the British Association for Cardiovascular Prevention and Rehabilitation (BACPR) recommend cardiac rehabilitation (CR) for patients post-CABG to prevent complication and improve the functional status and quality of life (QOL) (Piepoli et al., 2010; Thomas et al., 2010; Hillis et al., 2011; BACPR, 2017).

The National Institute for Health and Care Excellence (NICE) is an organisation that has an advisory role to the National Health Service (NHS) by providing evidence-based guidelines and quality standards to improve healthcare services in the UK. According to NICE, the recommendation is that patients post-CABG should wait 6 weeks before commencing CR (NHS, 2013). There has been clinical assumption and theory by many patients and clinicians in protecting patients after sternotomy (i.e., intentionally broken sternum bone) that is held together by 8 wires. Six weeks post sternotomy period of relative rest has become a routine practice after the surgery, assuming it will reduce complications. Despite the high-level advice from NICE, the source and reasoning for this are still based on clinical judgment and hypothesised theory rather than an evidenced-based optimum time for bone muscle repair. Therefore, commencing core CR within 6 weeks of referral is considered an early CR (Fell, Dale and Doherty, 2016).

The prolonged waiting time could be unnecessary and restrictive since no evidence supports the claim of an association between early exercise (CR) and sternum complication (Cahalin, LaPier and Shaw, 2011). In addition, although early CR is generally found to be safe and effective (Haykowsky et al., 2011) and is supported by BACPR (BACPR, 2017), there is a limited number of studies in the literature and clinical guidance that define what constitutes an early safe and effective CR exercise period for patients post-CABG.

Additionally, in the recent National Audit of Cardiac Rehabilitation (NACR) quality and outcomes report, which captures routine CR practice in the NHS, there is considerable variation in how long patients are waiting (NACR, 2018). Research using the NACR database showed an association between patients waiting longer and the decreased CR outcomes gained from the CR programme (Fell, Dale and Doherty, 2016). Moreover, it was stated in the NACR quality and outcomes report that the overall starting of CR is, on average, 50.0% of all eligible patients, which falls short of the target percentage of 85.0%

set by the NHS long-term plan (NHS, 2019). Achieving these targets would result in decreasing both the death rate and hospital admission by over 23 thousand and 50 thousand, respectively, by 2029 (NHS, 2019; British Heart Foundation, 2019b). Also, it was reported that there was a decrease in the number of patients who completed and attended the post-CR assessment compared by 23.0% to the number of patients who started CR (British Heart Foundation, 2019a).

In a recent PhD thesis, (al Quiet, 2018) research investigated 4 categories of determinants for the PCI population's starting CR in the UK using NACR data. The research looked into sociodemographic information (such as age, gender, and ethnicity), cardiac risk factors (such as hypertension, diabetes, physical inactivity), lifestyle and health status (such as smoking, comorbidities, previous cardiac event) and service level factors (e.g., waiting time, CR centre prescribed dose, supervised/self- delivered). It found that several of the factors were determinants for CR starting. The probability of CR starting decrease with factors such as older age, smoking or > 3 Comorbidities, while the probability increase by other factors, e.g., longer waiting time, being female or having a higher socioeconomic status (SES).

By conducting an observational registry-based study utilising NHS routine practice data, the research aims to study the association between waiting time and patients' post-CABG physical fitness, psychological health, and cardiovascular risk factors and the factors associated with not enrolling and completing CR. This will include carrying out a review of the literature and a critical review of key papers related to waiting time. Collectively this will give a comprehensive summary of the evidence together with current concepts and data and, through the critical appraisal, identify points of strength and weakness in related papers and their analyses to help shape this thesis methodology.

1.2 Cardiac Rehabilitation

1.2.1 Background

In the modern era of cardiology, defined by Rauch and colleagues as post-1995, CR has been investigated by a substantive number of different research methods, including RCTs and systematic reviews with meta-analysis (Rauch et al., 2016). This summary of evidence concluded that CR is presently effective for CVD on patient survival, morbidity, QOL, hospital of stay, risk factors and psychological health (Zheng et al., 2019; Dibben et al., 2018; van Halewijn et al., 2017; Anderson et al., 2016b; Rauch et al., 2016). Furthermore, CR has been defined by BACPR as:

"The coordinated sum of activities required to influence favourably the underlying cause of cardiovascular disease, as well as to provide the best possible physical, mental and social conditions, so that the patients may, by their own efforts, preserve or resume optimal functioning in their community and through improved health behaviour, slow or reverse progression of disease" (BACPR, 2017).

This definition encompasses the need for a comprehensive intervention approach to improve patients' functional status and modify cardiovascular risk factors.

Concerning patients following open heart surgery, CR services are delivered in 3 distinct phases in the UK (BACPR 2017) and Europe (Piepoli et al. 2016). The patient CR journey starts with acute in-hospital CR, which includes (post-surgery) light physical exercise and education sessions on the importance of being active and adjusting lifestyle to reduce cardiovascular risk factors. Phase II is extended when the patient is discharged from the hospital with advice on the importance of increasing physical exercise and making more healthy choices. Once the patient is deemed ready, they start outpatient core CR (sometimes referred to as phase III), which begins with an early initial CR assessment, including blood analysis, medical examination, physical fitness test, and psychological tests used to inform the individualisation of core CR. Following that, patients start a

comprehensive CR that covers the physical fitness part, with tailored graduated exercise training, as well as provides psychological and social support. After completing core CR, the patient undergoes a final CR assessment to measure the rehabilitation outcomes and set parameters for their long-term maintenance phase, where patients are encouraged to continue being active, join their community's exercise facilities, and maintain annual medical check-ups (BACPR, 2017).

1.2.2 CR Pathway of Care
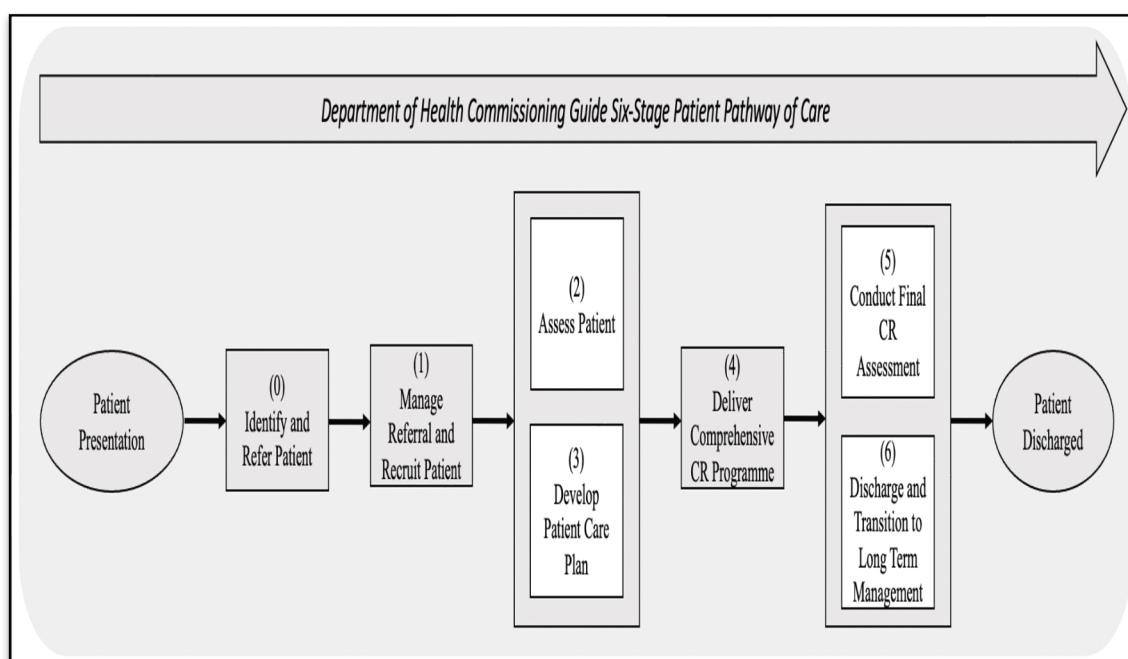
Figure 1.1 The Stages of the CR Pathway in the UK Setting
Reproduced from The Department of Health Commissioning Guide 6-Stage Patient Pathway of Care (BACPR, 2017).

The UK Department of Health Commissioning Guide for Cardiac Rehabilitation, working with BACPR, proposed a 6-stage pathway of care for cardiac patients in their effort to ensure the optimal utilisation and maximise benefits from the CR programmes (BACPR, 2017). The pathway, as shown in Figure 1.1, would start after the patient is presented with post-cardiac events and their eligibility for rehabilitation is established; that is when the first stage happens, where the patient receives a CR referral and is recruited to participate in a CR programme. In the second stage, patients would undergo a pre-CR assessment,

and the information collected would be used to develop a care plan in the third stage. After receiving a comprehensive CR programme in the fourth stage, the fifth stage patient would undergo the post-CR assessment and then discharge with long-term management in the sixth stage.

1.2.3 CR Beneficial Effects

A Cochrane systematic review conducted by Anderson et al. (2016) aimed to compare CR using exercise with usual care for patients with CVD. This is an updated review of a previous Cochrane published in 2011 where they focused on assessing the mortality rates, morbidity, and health-related quality of life (HRQL). The review included 14,486 participants within 63 RCTs. The majority of the participants were male, aged from 47.5 to 71.0 years and diagnosed mainly with post-myocardial infarction (MI), post-PCI and post-CABG. They reported that 27 trials had found CR effective in reducing cardiovascular mortality (risk ratio (RR): 0.74, 95% CI: 0.64, 0.86). Moreover, 15 trials maintained that there was a decrease in the risk of prolonged hospital stay (RR: 0.82, 95% CI: 0.70, 0.96) (Anderson et al., 2016b). They also report a significant recovery of HRQL scales, which is in accordance with the findings by Francis et al. (2019) in their recent meta-analysis (Anderson et al., 2016b; Francis et al., 2019). The Cochrane systematic review by Anderson et al. (2016) is currently the most extensive review encompassing 63 RCTs regarding CR and endorsing its effect on reducing mortality and hospital stay and improving HRQL for patients after non-surgical and surgical cardiac interventions.

In another study, van Halewijn et al. (2017), with objectives to assess the CR effectiveness on several outcomes of mortality, morbidity, and cardiovascular risk factors, published a systematic review and meta-analysis. There were 18 RCTs of CR (and no less than 6 months of follow-up), including 7691 subjects with CVD. Most participants were male, and the mean age range of the studies was 56 to 70 years. Four RCTs reported a reduction in cardiovascular mortality (RR 0.42, 95% CI: 0.21, 0.88). The incidence of MI and

cerebrovascular events were mentioned in 4 out of the 18 trials (N = 3416). Attributing it to comprehensive CR, they reported a drop in the incidents by RR=0.70 (95% CI: 0.54, 0.91) and RR=0.40(95% CI: 0.22, 0.74) for MI and cerebrovascular events, respectively. There was also a statistically significant reduction in the risk of both high systolic blood pressure −3.16 mmHg (95% CI: −5.55, −0.77) and LDL cholesterol −0.31 mmol/l (95% CI: −0.58, −0.04) (van Halewijn et al., 2017).

A meta-analysis was conducted to investigate whether CAD patients' risk factors and depression can be improved by CR and psychology therapy (Rutledge et al., 2013). They found 17 RCTs for CR and cardiovascular events and 13 RCTs for CR and depression and concluded that CR effectively decreases cardiovascular and depression and total mortality. In addition to CR's positive effect on depression (Zheng et al., 2019), a meta-analysis that included 20 trials found that CR reduces anxiety in post-MI patients.

A systematic review and meta-analysis method was used to measure how much the physical activity level of heart disease patients is affected by CR compared to the control group (Dibben et al., 2018). Participants of 6,480 within 40 RCTs were included, and they reported that CR had caused physical activity level improvement. In addition, Mitchell et al. (2018) undertook a systematic review and meta-analysis to evaluate the effect of exercise intensity on cardiorespiratory fitness (in the form of peak oxygen uptake (VO_{2peak})) (Mitchell et al., 2018). The review included 121 studies and 13,220 patients post-myocardial infarction and cardiac revascularisation, concluding that CR would improve cardiorespiratory fitness significantly.

The effect of CR has been investigated thoroughly across many countries and settings and endorsed firmly based on the evidence from the trials settings; however, as an example, the UK's NACR is reporting large levels of variation (British Heart Foundation, 2018), such as the time patients wait, and it is thus important to investigate whether these variations are presently associated with outcomes and differing levels of patient benefits.

1.2.4 RCTs About Waiting Time

The review of the literature identified 2 randomised clinical trials (RCT) that investigated waiting time: the SCAR and the SheppHeartCABG trial, as shown in Table 1.1.

Table 1.1 Recent Studies on the Waiting Time for Patients With Sternotomy/CABG

Early initiation of post-sternotomy cardiac rehabilitation exercise training (SCAR)	SheppHeartCABG trial-comprehensive early rehabilitation after coronary artery bypass grafting
Study Start Date: 15th July 2017 (completed) Location: England, UK.	Study Start Date: November 2014 (completed) Location: Copenhagen, Denmark.
Study Design: an assessor-blind randomised controlled trial.	Study Design: randomised clinical superiority trial with blinded outcome assessment.
Trial Objectives: To assess the effect of early "core" CR on: 1. Functional fitness. 2. Anxiety, depression and HRQL. 3. Compliance and adherence. 4. Cost-effective and safety.	Trial Objectives: To assess the effectiveness and harms of the comprehensive phase I CR on: 1. Functional fitness. 2. Anxiety, depression and HRQL. 3. Sleep disorder and pain. 4. Leg strength and endurance.
Planned Sample size (140) - Patients who are to undergo elective or emergency sternotomy for CABG or mitral/aortic valve replacement. - They will do 8 weeks of "core " CR exercise training and will be allocated into 2 groups where CR will start: 2 weeks (early CR) post-CABG. 6 weeks (usual care CR) post-CABG.	Planned Sample size (326) - Patients who are to undergo elective CABG. - They are allocated into 2 groups: - The intervention group is a phase I CR with an exercise training component and a psycho-educational component from admission until 4 weeks post-CABG + usual care. - The control group: only the usual care.

CR: cardiac rehabilitation. HRQL: Health-Related Quality of Life. CABG: coronary artery bypass grafting.

The SCAR trial, conducted in England, planned to recruit 140 patients post-CABG or valve replacement (mitral or aortic), both male and female, from the age ranging from 18 to 90 years old. They excluded patients with "significant limiting" comorbidities and patients diagnosed with neurological disorders or with a history of cerebral vascular accidents. Participants were allocated into 2 groups; the intervention group, which started 2 weeks post-surgery, and the control group started 6 weeks post-surgery. All participants received 8 weeks of CR. The 6-minute walking test (6MWT) was the primary outcome;

other functional fitness tests were also assessed, such as 5 times sit-to-stand, anxiety, depression and HRQL as secondary outcomes. They state that the study will be in one centre and recognise it would decrease the external validity (Ennis et al., 2018). They published their results in 2022, where they reported that for all the outcomes, there was an improvement for both groups without any significant differences and stated that early CR (the intervention group) were not inferior to usual care (control group) (Ennis et al., 2022).

On the other hand, the SheppHeartCABG trial was conducted in Denmark and recruited 326 patients post elective CABG from 18 and older. They excluded people with a limited cardiovascular function who could not perform walking and cycling exercises due to orthopaedic disorder. Each participant was assigned to one of 2 groups, the intervention or the control. Firstly, the intervention group received CR care from the first day until 4 months post-surgery, composed of 2 parts: physical exercise and psycho-educational; they also got the usual care for patients post-CABG. Secondly, the control care only received the usual care for post-CABG until 4 months post-surgery. Their primary and secondary outcomes were quite similar to the SCAR trial (Højskov et al., 2017). They published their primary results in 2019, where they reported that there were nonsignificant differences in 6MWT measurements, as well as in the secondary outcomes, between the 2 groups, except for the outcome for depression, as they reported that the intervention group were less likely to be depressed (OR: 0.46, 95% CI: 0.22, 0.97) (Højskov et al., 2019).

The above studies focused on effectiveness, which is an important requirement as part of evidence-based practice; however, like many clinical trials, their sample populations were not fully representative of the eligible population. For instance, patients recruited to the SCAR trial had a mean age of 63.0 years (84.0% male); for the SheppHeartCABG trial, it was 65.0 years (87.0% male). In this PhD thesis, the mean age for UK routine practice

post sternotomy patients was 66.0 years (77.0% male). In essence, this thesis is based on a larger, more inclusive and representative population. This further supports the NICE recommendation that observational studies taking account of data from real-world settings represent a vital part of the evidence base (NICE, 2022).

This thesis will address the above gaps with an observational study using routine practice data from all eligible patients who attended NHS CR.

1.3 Research Question

What is the level of association between waiting time and CR starting, completion and outcomes in patients following open-heart surgery?

1.4 Research Aims

The aims of this research:

A. To identify factors influencing the waiting time for cardiac rehabilitation (CR).

B. To determine the level of association between waiting time and starting, completion and outcomes for patients post-CABG, post-valve surgeries or combined CABG and valve surgeries.

1.5 Research Objectives

1. Carry out a review of the literature identifying factors associated with waiting time, utilisation and outcomes in post-CABG, post-valve surgeries or combined CABG and valve surgeries.

   - Clarify which of the literature-based factors are currently recorded in the NACR database and also identify factors not captured by NACR but nerveless important to inform the discussion of the thesis.

2. Test the extent to which literature-based factors are associated with utilisation and outcomes for patients following CABG, valve surgeries or combined CABG and valve surgeries.

3. Design, conduct, analyse and write up 3 observational studies using national audit data for patients following CABG, valve surgeries or combined CABG and valve surgeries:

- Study 1: determine the level of association between waiting time and starting CR.

- Study 2: determine the level of association between waiting time and CR completion.

- Study 3: determine the level of association between waiting time and routinely reported patient outcomes (e.g., physical fitness, psychological health, and cardiovascular risk factors outcomes).

1.6 Structure of the Thesis

This thesis is presented over 7 chapters that cover the following: investigating and appraising the literature, devising the thesis methodology, carrying out 13 regression analyses relating to CR utilisation and outcomes, and writing a synthesis that draws from the analyses results, completed by a conclusion and recommendations.

The first chapter is comprised of the introduction section, the outline of the thesis structure and the literature review. The introduction provides an establishment for the scarcity of recent research relating to waiting time, starting, completing, and benefiting from CR for patients post open-heart surgeries. Next, the thesis outline is presented to summarise the aims and objectives overriding the research question. Further, the literature review focused on summarising and critically appraising existing research.

The second chapter encompasses the thesis methodology detailing the steps followed in conducting the research. The methodology includes the research design, defining the data source, discussing the ethical consideration, and describing the implemented statistical analyses.

Chapters 3-5 cover the regression analyses for starting, completing and CR outcomes. Each chapter presents the research performed to answer the thesis questions by analysing the data and writing a discussion of the findings and conclusion.

Chapter 6 showcases the thesis synthesis analysis, where the findings from chapters 3-5 were brought together and examined. Finally, chapter 7 is a synthesis of all chapters leading to a final conclusion for the whole PhD thesis and the recommendations and recommended further research.

1.7 Literature Review

1.7.1 Background

A literature review is "A critical summary and assessment of the range of existing materials dealing with knowledge and understanding in a given field. Its purpose is to locate the research project to form its context or background and to provide insights into previous work" (Barron, 2006), in addition to understanding different study methodologies and approaches. Moreover, by performing a literature review, it is possible to ascertain any gaps in the literature and identify areas that can bridge them through current research (Wellington et al., 2005). Furthermore, it can help the researcher pinpoint specific individual studies or findings that can contribute to research (Boaz and Sidford, 2011). Thus, the objectives of this literature review were to identify and assess all relevant studies that had investigated the factors associated with waiting time, utilisation and outcomes in patients following CABG.

1.7.2 Methods

1.7.2.1 Eligibility Criteria

The researcher identified the search PICO elements (population, intervention, comparison, outcome) listed in Table 1.2. The PICO was incorporated into the inclusion and exclusion criteria, which will be beneficial for minimising bias, narrowing the scope

of the research objectives, and enabling the selection of all the eligible contributing publications. The eligibility criteria cover 6 areas concerning the studies' population, objectives, comparative groups, measured outcome, publication, and language, while no specific research design will be included or excluded (see Table 1.3).

Table 1.2 The Research PICO

Population	Is the population or the patient group CABG?
	Was the study population recruited between 2000 to the current date?
Intervention	Is the intervention a recognised form of CR
	Was the waiting time of CR delivery defined in the study intervention?
Comparison	No comparator
Outcome	Is the focus of the paper on clinical outcomes?

CABG: coronary artery bypass grafting. CR: cardiac rehabilitation.

Table 1.3 The Research Eligibility Criteria

The criteria	Inclusion criteria	Exclusion criteria
Population	Older than 18 years Diagnosed with CAD Undergone CABG	Younger than 18 Years
Objective	Inspecting the effect of waiting time in patients of post-CABG	No explicit mention of when early CR was started
Comparative groups	Patients participated in a recognised form of CR (from 2000 onwards) within 12 months post-CABG.	No mention of CR, but a mention of any other form of exercises
Measured Outcome	Include any types of outcomes, such as the outcomes of physical fitness (e.g. 6MWT), psychological health (e.g. Depression), and cardiovascular risk factors (e.g. diabetes mellitus).	No specific reporting for patients post-CABG
Publication	Full article published from 2000 onwards.	Abstracts that were not published in full articles
Language	Published in the English language	Any paper not published in the English language

CABG: coronary artery bypass grafting. CAD: coronary artery disease. CR: cardiac rehabilitation.

In the BACPR publication regarding CR standards and core components (BACPR, 2017), among patients post-open-heart surgeries, they identified patients post-CABG as their main beneficiary of CR services, while they mentioned patients post heart valve surgeries as someone the service provider aims to offer to. The population of the literature review focused on patients post-CABG, which was considered broad enough to answer the research question. Moreover, in a recent Cochrane review (Abraham et al., 2021) that aimed to examine the effect of CR on patients post-valve surgeries, their meta-analysis included only 6 RCTs and 354 patients. The authors reported their inability to draw clear conclusions regarding the impact of CR on patients post-valve surgeries. Since the existing Cochrane review found the evidence to support CR itself as intervention is lacking, in addition to there being no mention of waiting time in the 6 RCTs, the researcher opted out from including patients post-valve surgeries to the original literature review or the update since it was deemed unlikely to provide any new information or studies and only serve to increase the search words and sensitivity.

1.7.2.2 Databases Searched

A search strategy was developed in collaboration with an Information Specialist (KW) from the Centre for Reviews and Dissemination (CRD). The CRD is a research centre located at the University of York and aims to conduct systematic reviews and meta-analyses that would contribute to evidence-based medicine and influence positive changes in NHS policies. The search strategy used terms focused only on the population (people with CABG) and the intervention (CR) without including any terms for outcomes. In other words, limit the search strategy to include population and intervention terms; after that, the reviewer would manually apply exclusion and inclusion criteria for outcomes as an approach to increase the sensitivity of the results and ensure the inclusion of all related papers. Of course, this meant more results in the search, but overall, the search was more inclusive, which is a trade-off to identifying the maximum number of

studies. In addition, the outcomes were limited and allowed the reviewer to get a better understanding of the subject area, a spinoff benefit from performing the literature review. The original search for the literature was conducted on 4th April 2019 using Ovid MEDLINE (Ovid, ALL <1946 to 3rd April 2019>), Embase (Ovid) and CENTRAL (Cochrane Central Register of Controlled Trials, 1996 to present) (see Appendix A). MeSH terms (Medical Subject Headings) combined with keywords such as the following were used to identify the records that address CR in the CABG population: Coronary Artery Bypass, Myocardial Revascularization, Cardiac Rehabilitation, and Heart Rehabilitation. CR care has experienced crucial changes due to the publication of updated CR guidelines and standards in the 90s and 2000s; there is a time limitation (2000 and onwards) on the publications and populations included in the search (Sumner, Harrison and Doherty, 2017). This differs from Cochrane systematic reviews, which include trials as old as 1975; however, since this research aimed to assess CR in modern times, it will be more appropriate to limit this review to 2000 and onwards.

Update searches were run by an Information Specialist (HF) on 13th April 2022, using all the databases from the original searches. The updated searches used identical strategies to the original searches without date limits. In addition, the results of the databases were deduplicated against each other in a separate EndNote 20 Library before being merged with the results of the original EndNote Library and deduplicated for a second time. This ensured that all new records retrieved by the search and not screened previously could be retrieved, which yielded 541 new records. See Appendix B for the entire search strategies of the updated searches.

1.7.2.3 Studies Selection

The records found from searching the database were downloaded to a reference management software (EndNote X9). Then began the first stage of the studies selection process, which involved finding and removing the duplicated records and finding and

removing records published before the year 2000. Existing records were included or excluded if their title and abstract met the eligibility criteria. This was done with the notion of being more inclusive as a cautionary measure to avoid leaving out relevant and essential articles. That was followed by the second stage of the studies selection, which required the review of the full published papers of the included articles based on the eligibility criteria; in addition, there was the filtering of any records about CR utilisation into its group. In cases where the fully published papers were unavailable either by the "find full text" feature of the reference management software or by the researcher using various search resources, the reviewer utilised the "Interlending and Document Supply". This service by the University of York allows researchers to request texts to be provided by the full papers of the articles if possible. The study selection process (in both stages) was carried out by the primary researcher (KA). For the purpose of ensuring the validity of the process, during the first stage, a random selection of included and excluded articles was shared with the second supervisor (AH), followed by cross-matching the decisions for each study with a third reviewer (PD) in case of disagreement.

1.7.2.4 Data Extraction and Quality Assessment

Extracting data from the selected studies should reflect its inclusion eligibility and incorporate only relative data; a form was created based on PICO and the eligibility criteria.

The data extracted would capture the study characteristics of the first author's name and year of publication, also the study design and location. Further, it would show both methodology (types and numbers of participants and interventions including CR types) and the primary and comparative measured outcomes. The data was extracted by the researcher (KA).

It is critical to utilise reliable information in the research, so by using critical appraisal, the researcher can assess the quality of the studies and judge whether the literature dealt

with is relative, and the results can be used confidently (Burls, 2009). Critical appraisal is defined as "the process of systematically examining research evidence to assess its validity, results and relevance before using it to inform a decision" (Hill and Spittlehouse, 2001). Different study designs come with different used methodologies, which in turn have a different quality that would introduce bias to the research and compromise its "internal validity", which means how much results deviate from the truth; this variance in the quality can be weighted in terms of high or low, by implanting a critical appraisal tool (Walker, 2014).

The critical appraisal can be accomplished using tools to assess the research according to its design or type. The Physiotherapy Evidence Database (PEDro) is an 11-point scale used to assess the quality of RCTs, more specifically to assess their validity (internal and external) and the possibility of deciphering the results (PEDro, 1999). In 1998, Verhagen and colleagues at the Department of Epidemiology, University of Maastricht founded a quality assessment criteria list called (the Delphi list), on which PEDro is based (Verhagen et al., 1998; PEDro, 1999). The PEDro scale was tested and found reliable and valid (Maher et al., 2003; De Morton, 2009; Macedo et al., 2010). According to the PEDro guidelines, there are 11 criteria with 2 possible answers (yes or no) to measure the validity of the study, with the first criterion being about the external validity but does not contribute to the total score, while the rest of the criteria from 2 to 11 about the internal validity and are used for the total score out of 10 by appointing a point for every yes. The researcher can use the PEDro scale in 2 ways firstly, by obtaining the scores published in the PEDro database (https://www.pedro.org.au) and having the benefit of the study score being externally validated, and secondly, when the score is not published in the database, the appraisal can be performed by the researcher using the scale (PEDro, 1999; Maher et al., 2003).

For other study designs, the Joanna Briggs Institute (JBI), a research organisation within the Faculty of Health Sciences at the University of Adelaide, developed the JBI critical appraisal tools, which are used to evaluate both the quality of the methods and the bias of research. The reason for choosing the JBI is that the developer provides a family of tools that cover many study designs, unlike other developers. The JBI critical appraisal tools can be used for cross-sectional studies, cohort studies, non-randomised experimental studies, systematic reviews, and research syntheses (Moola et al., 2017; Tufanaru et al., 2017; Aromataris et al., 2015). The JBI critical appraisal checklist can go from 6 questions up to 11 depending on the research design, with the possible responses being yes, no, unclear, or not applicable. A score is awarded only when the answer is yes, which is then summarised to calculate the total score.

Due to the use of different critical appraisal tools according to the included different design studies, during this research, the obtained score for every study will be normalised and expressed in the form of a percentage, i.e., will calculate what the percentage of obtained points out of the total scale points is, e.g., 9 is 82.0% out of a maximum of 11 (100%). After normalising the scores for all the selected studies, the quality and the risk of bias will be categorised as the following: high quality (low risk of bias) if the study scored 70.0% or more, moderate quality (moderate risk of bias) for 69.0% to 50.0%, and low quality (high risk of bias) for less than 50.0% (Gouvêa et al., 2018; Melo et al., 2018; Goplen et al., 2019). Regardless of their quality classification, all the selected studies will be included to reach the research's first objective of providing a comprehensive description from the literature of the effect of waiting time on patients post-CABG.

1.7.2.4.1 PEDro vs JBI Tool

The PEDro tool and database are designated primarily for RCT studies (and systematic reviews) in the physiotherapy and rehabilitation research field by providing either the appraisal or the tool to be carried out. However, since JBI was used for other forms of

research design, there was a requirement to test if the score of RCTs critically appraised by PEDro was equivalent to if it was done using the JBI critical appraisal tool. This was accomplished by randomly selecting 5 out of 11 RCTs (the number of RCTs in the original research in 2018) with 3 different qualities (high, moderate, and low) according to the PEDro scale, then critically appraising them by the JBI tool for RCTs. Then compare the quality of the trials with the two tools, and they would be considered equivalent if they match in quality in more than half of the trials and there is no drop or rise in the quality between high and low (Appendix C). As a result of the conducted comparison, it can be said that PEDro and JBI are equivalent to RCTs.

1.7.3 Literature Review Results

The preferred reporting items for systematic reviews and meta-analyses (PRISMA) flow chart (see Figure 1.2) shows the study selection and findings, which was updated to include the new records found since the first literature search, which is considered good practice (Moher et al., 2009). Three thousand five hundred forty-one records were found when searching the database; 929 were duplicates. During the review, 2,612 titles and abstracts were screened and recorded; as a result, 1,228 papers were excluded. To determine eligibility, 1,384 full-text journal articles were assessed, 27 were included in the review, and 1,357 were excluded for not meeting the inclusion/exclusion criteria.

The data extraction sheet (see Table 1.4) shows the selected studies' relative data and quality assessment scores. Out of the 27 studies, 15 were RCTs, 7 were quasi-experimental studies, and 5 were cohort studies. The year of publication goes from 2004 to 2022, with the origin of publication from various locations such as Europe, Asia, and Oceania. While 21 studies had patients post-CABG as their only participants, 6 studies had an additional type of participant, such as patients post-valve replacement. Regarding the type of CR, half of the studies mentioned phase I CR in the acute hospital period as their intervention, with the other half being core CR delivery as part of an outpatient

provision. Additionally, 21 studies assessed the effect of early CR and only 5 compared early CR vs late CR.

Identification

Records identified through database searching.
(n =3,541)

Screening

Records after duplicates removed
(n =2,612)

Records screened for titles and abstracts.
(n = 2,612)

Records excluded
(n = 1,228)

Eligibility

Full-text articles assessed for eligibility
(n = 1,384)

Full-text articles excluded, with reasons (n =1,357)
Not relevant (no CABG population, no CR program, no assessing of the CR, no assessing of CR timing) (n =733)
Not fully published conferences abstracts (n =377)
Review, Editorials & Guidelines Articles (n=201)
Letters & Comments (n=46)

Included

Studies included in 2019 review
(n = 22)

Studies included in the 2022 review update
(n = 5)

Total number of the Studies included in the review
(n = 27)

Figure 1.2 PRISMA Flow Chart Shows the Study Selection for the Original Search (2019) and the Updated Search (2022)

Table 1.4 Data Extraction Sheet Summarising Details Population and Key Findings of All Included Studies

Data extraction sheet Study name and design and country	Quality level (Score %)	Number and Diagnosis of Participants	CR Phase	Effect of Early CR OR Early CR vs late CR	Intervention/s	Main Outcome Measures
Marzolini et al. (2015) Cohort Study Canada	High Quality (91.0)	6,497 post-CABG	Core CR	Early CR vs late CR	Core CR in Canada	Total Wait Time (between the surgery and starting CR): comparing patients between (2001-2006) and (2007-2012) the latter group had short referral wait time and longer total wait time, which correlates with being older; female; employed; longer drive time to CR; lower neighbourhood socioeconomic status; higher resting systolic blood pressure; abdominal obesity; current cigarette smoking; and a diagnosis of heart failure, diabetes mellitus, MI, cardiac arrest, cardiomyopathy, stroke, and valve surgery. Total wait time was negatively correlated with change in VO$_{2peak}$, diastolic blood pressure, and attendance to CR sessions, while positively correlated with change in body fat and resting heart rate. Longer total wait time was negatively correlated with not completing CR.
Fell, Dale and Doherty (2016) Cohort Study UK	High Quality (82.0)	7,783 post-CABG, 4,280 Post-MI 13,331 Post MI-PCI 7,505 PCI	Core CR	Early CR vs late CR	Core CR in the UK	Wait time exceeded recommendations for post-CABG surgery patients.

Table 1.4 Data Extraction Sheet Summarising Details Population and Key Findings of All Included Studies

Data extraction sheet Study name and design and country	Quality level (Score %)	Number and Diagnosis of Participants	CR Phase	Effect of Early CR OR Early CR vs late CR	Intervention/s	Main Outcome Measures
Pack et al. (2015) Cohort Study USA	Moderate Quality (55.0)	112 post-CABG 69 valve replacement 59 post-MI	Core CR	Early CR vs late CR	Lower limbs exercises (e.g., walking) Upper limbs exercises (e.g., stretching)	Patients post-CABG who started CR early had fewer adverse cardiac events compared to the patients post-CABG who had waited longer to start CR (16.0% vs 30.0%).
Ennis et al. (2022) RCT UK	Moderate Quality (60.0)	71 post-CABG 74 valve surgeries 13 CABG/ valve surgeries	Core CR	Early CR vs late CR	Intervention group: core CR start 2 weeks post-op. control group: core CR start 6 weeks post-op	6MWT: nonsignificant differences between the groups.
Dong et al. (2016) RCT China	Low Quality (40.0)	106 post-CABG	Phase I CR	Early CR vs late CR	Intervention group: CR in ICU (education, training). Control: usual care started after ICU	Intervention group had significantly decreased duration of mechanical ventilation, shorter ICU stay, and short hospital stays.

Table 1.4 Data Extraction Sheet Summarising Details Population and Key Findings of All Included Studies

Data extraction sheet Study name and design and country	Quality level (Score %)	Number and Diagnosis of Participants	CR Phase	Effect of Early CR OR Early CR vs late CR	Intervention/s	Main Outcome Measures
Hirschhorn et al. (2012) RCT Australia	High Quality (90.0)	64 post-CABG	Phase I CR	Effect of Early CR	Intervention group 1: stationary cycling and usual care. Intervention group 2: walking exercises and usual care	There were nonsignificant differences between the intervention groups in the 6MWT, 6-min cycle assessment, SF-36 score, hospital length of stay, or incidents of atrial fibrillation.
Hirschhorn et al. (2008) RCT Australia	High Quality (70.0)	93 post-CABG	Phase I CR	Effect of Early CR	Intervention group 1: usual care and walking exercise. Intervention group 2: usual care, walking exercises and breathing exercises. Control group: usual care	6MWT: Both intervention groups were statistically higher at discharge than the control group. Vital capacity and HRQ: no difference between the 2 intervention groups.
Højskov et al. (2019) RCT Denmark	Moderate Quality (60.0)	326 post-CABG	Phase I CR	Early CR vs late CR	Intervention group: comprehensive early CR that continues 4 weeks post-operation. Control group: usual care	6MWT: nonsignificant differences between the groups. HADS-Depression ≥8: there were significant differences between the groups. Adherence: Most 59 (54.0%) patients attended less than 50.0% of the exercise programme. Safety: it was safe.

Table 1.4 Data Extraction Sheet Summarising Details Population and Key Findings of All Included Studies

Data extraction sheet Study name and design and country	Quality level (Score %)	Number and Diagnosis of Participants	CR Phase	Effect of Early CR OR Early CR vs late CR	Intervention/s	Main Outcome Measures
Borzou et al (2018) RCT Iran	Low Quality (40.0)	60 post-CABG	Phase I CR	Effect of Early CR	Intervention group: 3 sessions (education and exercise programme). Control group: routine care	The interventional group had statistical higher self-efficacy at discharge and one-month follow-up.
Stein et al. (2009) RCT Brazil	Moderate Quality (50.0)	20 post-CABG	Phase I CR	Effect of Early CR	Intervention group: pulmonary care modalities, body exercises and usual care Control: the usual care (medical and nursing care)	Maximal inspiratory pressure: no change in the intervention group and a significant reduction in the control group. 6MWT: the intervention group has increased at 7-day postoperatively. VO_{2peak} : the intervention group had increased at 30-day postoperatively and correlated with maximal inspiratory pressure.
Ximenes et al. (2015) RCT Brazil	Low Quality (40.0)	34 post-CABG	Phase I CR	Effect of Early CR	Intervention group: resistance exercise and usual exercise. Control group: usual exercises	Pulmonary function: nonsignificant difference between groups. The predicted distance in 6MWT measured functional capacity at hospital discharge: it did not change for the intervention group but decreased for the control group.

Table 1.4 Data Extraction Sheet Summarising Details Population and Key Findings of All Included Studies

Data extraction sheet Study name and design and country	Quality level (Score %)	Number and Diagnosis of Participants	CR Phase	Effect of Early CR OR Early CR vs late CR	Intervention/s	Main Outcome Measures
van der Peijl et al. (2004) RCT Netherlands	Moderate Quality (50.0)	246 post-CABG	Phase I CR	Effect of Early CR	Intervention group 1: high-frequency exercise programme. Intervention group 2: low-frequency exercise programme	Intervention group 1 achieved functional milestones faster, i.e., sitting in a chair, walking in the room; walking in the ward; group exercise therapy, and climbing stairs.
Thapa and Pattanshetty (2016) Quasi-Experimental Study India	Low Quality (44.0)	50 post-CABG	Phase I CR	Effect of Early CR	Intervention: chair aerobic exercises	Significant improvement in systolic blood pressure, heart rate and 6MWT:
Mendes et al. (2011) Quasi-Experimental Study USA	High Quality (100)	44 post-CABG	Phase I CR	Effect of Early CR	Intervention: short-term in-patient supervised exercise programme	Heart rate variability: Intervention group 2 had significantly improved compared to Intervention group 1.

Table 1.4 Data Extraction Sheet Summarising Details Population and Key Findings of All Included Studies

Data extraction sheet Study name and design and country	Quality level (Score %)	Number and Diagnosis of Participants	CR Phase	Effect of Early CR OR Early CR vs late CR	Intervention/s	Main Outcome Measures
Mendes et al. (2010) RCT USA	Moderate Quality (50.0)	47 post-CABG	Phase I CR	Effect of Early CR	Intervention group: short-term in-patient supervised exercise programme Control group: usual care	Heart rate variability: Intervention group had significantly improved compared to the control group.
Ratajska et al. (2020) RCT Poland	Low quality (40.0)	80 post-CABG	Phase I CR	Effect of Early CR	Intervention: CR combined with soft tissue manual therapy using myofascial release techniques	The intervention group had significant improvement in pain and fatigue levels (on the fourth and sixth-day post-op), improvement in breathing difficulties, and physical fitness (on and sixth-day post-op).
Faizan Hamid et al. (2022) RCT Pakistan	Moderate Quality (50.0)	54 post-CABG	Phase I CR	Effect of Early CR	Intervention: CR combined with lower limb exercises using a paddler	Improvement for quality-of-life, functional independence and arterial blood gasses were significantly higher in the intervention group compared to the control group.

Table 1.4 Data Extraction Sheet Summarising Details Population and Key Findings of All Included Studies

Data extraction sheet Study name and design and country	Quality level (Score %)	Number and Diagnosis of Participants	CR Phase	Effect of Early CR OR Early CR vs late CR	Intervention/s	Main Outcome Measures
Tsai, Lin, and Wu (2005) RCT Taiwan	Moderate Quality (50.0)	30 post-CABG	Core CR	Effect of Early CR	Intervention group: 3-week core CR Control group: no core CR.	Resting heart rate: Intervention group has significantly reduced compared to the control group. Heart rate over 1 min: Intervention group had significantly increased recovery compared to the control group.
Plüss et al. (2008) RCT Sweden	Moderate Quality (60.0)	127 post-CABG 97 post-MI	Core CR	Effect of Early CR	Intervention group: in-patient care, stress management cooking sessions and dietary counselling and usual care Control group: usual care	Exercise Performance measurements: nonsignificant differences between the groups after a 1-year follow-up. Blood lipids, blood pressure and glucose metabolism, inflammation and cell counts showed nonsignificant differences between the groups after a one-year follow-up.
Nishitani et al. (2013) Quasi-Experimental Study Japan	High Quality (78.0)	78 post-CABG	Core CR	Effect of Early CR	Intervention group: 6-months core CR that started 6–8 days after CABG	Significantly decreased muscle strength and exercise tolerance in the pre-CR and post-CR in the DM group compared to the no-DM group. Both groups had a significant increase in exercise tolerance and muscle strength. Post-CR, muscle mass was significantly improved in the no-DM group. There was a correlation between the percentage change in muscle strength and glycosylated haemoglobin in patients undergoing CR after CABG.

Table 1.4 Data Extraction Sheet Summarising Details Population and Key Findings of All Included Studies

Data extraction sheet Study name and design and country	Quality level (Score %)	Number and Diagnosis of Participants	CR Phase	Effect of Early CR OR Early CR vs late CR	Intervention/s	Main Outcome Measures
Massaro et al. (2014) Quasi-Experimental Study Italy	Moderate Quality (56.0)	60 post-CABG	Core CR	Effect of Early CR	Intervention: 4 weeks of in-hospital CR, then 3 months of follow-up at the outpatient clinic.	Oral Glucose Tolerance Test: At baseline, 28.3% had normal glucose tolerance, 41.6% had impaired glucose tolerance, and 30.1% had type 2 diabetes mellitus. Post CR programme, the number of patients with type 2 diabetes mellitus was significantly decreased, and the number of normal glucose tolerance patients had significantly increased. 6MWT: at baseline, type 2 diabetes mellitus and impaired glucose tolerance patients showed worse performances but had a similar improvement after 4 weeks of training.
Szczepanska-Gieracha et al. (2012) Quasi-Experimental Study Poland	Moderate Quality (56.0)	50 post-CABG	Core CR	Effect of Early CR	Intervention: 3 weeks CR	Post-CR, Severe depressive symptoms were accompanied by high anxiety values and low acceptance of illness. Depressed patients had no improvement in the subjective assessment of exertion or reduction of state anxiety. Women showed more severe depressive symptoms, a higher personality tendency to anxiety, and poorer rehabilitation results.
Socha, Wronecki and Sobiech (2017) Quasi-Experimental Study Poland	Moderate Quality (67.0)	65 post-CABG	Core CR	Effect of Early CR	Intervention: early CR	Body mass and BMI: Decreased in men < 65 and ≥ 65 years and women < 65 years.

Table 1.4 Data Extraction Sheet Summarising Details Population and Key Findings of All Included Studies

Data extraction sheet Study name and design and country	Quality level (Score %)	Number and Diagnosis of Participants	CR Phase	Effect of Early CR OR Early CR vs late CR	Intervention/s	Main Outcome Measures
Hansen et al. (2009) Quasi-Experimental Study Belgium	Moderate Quality (67.0)	238 post-CABG 439 post-PCI	Core CR	Effect of Early CR	Intervention group: 3-months core CR Control group: no core CR.	The intervention group compared to the control group cardiovascular events (14.0% vs. 4.7%), acute myocardial infarction (3.2% vs. 0.0%) and death (5.4% vs. 0.7%), significantly higher in the control group.
Doimo et al. (2019) Cohort Italy	High Quality (82.0)	353 post-CABG 378 STEMI 265 NSTEMI 284 post-PCI	Core CR	Effect of Early CR	Group 1: early CR. Group 2: no CR.	5-year composite endpoint incidence of hospitalisation for cardiovascular causes and cardiovascular mortality: for CABG patient, participation in the CR programme were an independent predictor of the lower occurrence of the composite primary outcome.
Skomudek, Waz and Rozek-Piechura (2019) RCT Poland	low quality (40.0)	120 post-CABG	Core CR	Effect of Early CR	Intervention for group 1: 8 weeks of CR with a resistance training Intervention for group 2: 8 weeks of CR with a resistance training	Operated legs in group 2 had significantly lower average temperature and higher leg venous pump in post-CR than pre-CR. The muscle function increased for both groups' operating limb to non-operating limb levels, but group 2 showed more nonsignificant differences between the two lower limb measurements.

Table 1.4 Data Extraction Sheet Summarising Details Population and Key Findings of All Included Studies

Data extraction sheet Study name and design and country	Quality level (Score %)	Number and Diagnosis of Participants	CR Phase	Effect of Early CR OR Early CR vs late CR	Intervention/s	Main Outcome Measures
Origuchi et al. (2020) Cohort Japan	High quality (73.0)	346 post-CABG	Core CR	Effect of Early CR	Intervention group: supervised exercise sessions, educational classes, individual counselling, and home exercise Control group: no CR	Intervention group: showed a significant increase compared to the control group in $VO_{2\ peak}$ and anaerobic threshold and a better long-term prognosis.

CABG: coronary artery bypass grafting. CR: cardiac rehabilitation. MI: myocardial infarction. VO_{2peak}: peak oxygen uptake. PCI: percutaneous coronary intervention. %: percentage. ICU: intensive care unit. 6MWT: 6 minutes walking test. SF-36: the short form 36 health survey questionnaire. Min: minute. HRQL: Health-Related Quality of Life. HADS-Depression: Hospital Anxiety and Depression Scale (Depression). DM: diabetes mellitus. BMI: body mass index. STEMI: segment elevation myocardial infarction. NSTEMI: non-ST-elevation myocardial infarction.

1.7.3.1 Early CR vs Late CR

1.7.3.1.1 Early CR vs Late CR - Core CR Phase

This section is the main focus of the review that will help inform the research and clinical practice by investigating the association between early and late core CR using various CR outcomes, which are more in line with the SCAR trial (Ennis et al., 2022).

In a high-quality cohort study by Marzolini et al. (2015), they aimed to examine the effect of early CR vs late CR on utilising CR services, abdominal obesity, and functional capacity in addition to measuring the correlation between participants' sociodemographic, geographic, and clinical data and the waiting time, i.e., the duration between the CABG surgery and starting the CR. The study recruited 2,087 patients post-CABG between 2001–2006 and 1,561 patients post-CABG between 2007–2012, all receiving comprehensive core CR. Comparing patients between (2001-2006) and (2007-2012), the latter group had a shorter treatment day-to-referral wait time and a longer referral-to-start CR wait time which correlates with being women; older; having employment; having lower SES; having higher resting systolic blood pressure; abdominal obesity; current smokers; diagnosed with heart failure, diabetes mellitus, stroke, and valve surgery. In addition, there was a significantly negative correlation between wait time and change in VO_{2peak}, diastolic blood pressure, and not completing CR, while positively correlated with changes in body fat and resting heart rate. This study concludes that the longer patients wait to start CR, the higher the possibility of dropping and not completing the CR programme and having poor outcomes (Marzolini et al., 2015).

In another high-quality cohort study by Fell, Dale and Doherty (2016), the authors studied the implications of waiting time on physical fitness. The study sample was cardiac participants who had their data in the NACR from 2012 to 2015, which included 7,783 patients post-CABG who were grouped "CR on time" if they started CR 0–42 days between CR referral and starting core CR and grouped "delayed CR" for (43–365 days)

waiting time. The physical fitness outcome was measured by incremental shuttle-walk test (ISWT), patient-reported physical activity level (150 min/week: yes/no) and Dartmouth Quality of Life for physical fitness (healthy status score 1–3, non-healthy status score 4–5). The study found that the waiting times often exceeded the recommendations for patients post-CABG, with 63.0% starting CR late. In addition, the research found that the improvement of post-CR physical fitness for late CR starting was less than the improvement in early CR starting; furthermore, wait time had a significant association with physical fitness, i.e., the longer wait time was associated with a decrease in physical fitness outcomes (Fell, Dale and Doherty, 2016).

In a moderate-quality cohort study by Pack et al. (2015), they explored the safety of early CR starting (less than 2 weeks), more specifically, the association between early CR and adverse cardiac events. The study included 112 patients post-CABG and compared the first adverse cardiac events for the early CR and the late CR participants. They concluded that patients post-CABG who started CR early had fewer adverse cardiac events than those who had waited longer to start CR (16.0% vs 30.0%, log-rank p-value = 0.037), which means that early CR is not only safe but also could decrease the adverse cardiac events (Pack et al., 2015).

In moderate-quality RCT by Ennis et al. (2022), they tested the impact of early core CR (2 weeks post-op) versus usual core CR (6 weeks post-op). Recruiting patients post-sternotomy (CABG, valve surgeries, and CABG/valve surgeries), they allocated 80 patients to the control group and 78 to the intervention group. All underwent 8 weeks of core CR; however, the control group started 6 weeks after the surgery, while the intervention started earlier, 2 weeks from the sternotomy. The primary outcome was 6MWT, and both groups showed an improvement after CR from the baseline measurements, i.e., 243.9 (SD = 144.2) m to 491.4 (SD = 92.9) m for the control group and 209.1 (SD = 117.6) m to 484.1 (SD = 95.9) m for the intervention group. Furthermore,

they reported that the intervention group (early core CR) was not inferior to the control group (usual core CR) since they showed a difference in mean change for 6MWT (28 m), the non-inferiority margin 35 m, (95% CI: −11, 66, p-value = 0.16). Also, both groups showed improvement in the secondary outcomes (functional lower extremity muscular strength, handgrip strength, anxiety, depression and HRQOL) with nonsignificant differences. Concerning the safety of the two approaches and experiencing adverse events, both groups had incidents of untoward medical occurrence, yet there was no difference between them (Ennis et al., 2022).

It is critical to point out some issues with this study, such as the potential bias of the results and, subsequently, the effectiveness of the intervention, which may occur due to the high number of dropouts, as out of the 158 participants, there were 40 participants (25.0%) who had dropped for various reasons (Elkins et al., 2010). Moreover, there is an age difference between both groups; the mean age for the intervention group is 61.6 (SD = 12.6) years, which is younger than the control group, 64.0 (SD = 10.3) years, and age was not factored in the analysis even though it is a significant independent variable for 6MWT measurements (Casanova et al., 2011). Furthermore, the choice of 6MWT as a primary outcome measurement may have been influenced by the "ceiling effect" since the control group started the study with a high 6MWT baseline that could limit their scope of change. That is, the 6MWT baseline measurement was already high, which made it difficult to detect any improvement. On the other hand, the intervention group started with a lower 6MWT baseline that would allow for more improvement to be achieved (Frost et al., 2005). Lastly, the study was not adequately powered to allow for inferential statistics regarding the secondary outcome nor the reporting on the safety of the intervention.

1.7.3.1.2 Early CR vs Late CR - Phase I CR (Acute Hospital Period)

In a low-quality RCT by Dong et al. (2016), they investigated if early phase I CR during intensive care unit (ICU) stays would be more beneficial than late phase I CR after leaving the ICU ward. The 106 (53 for each intervention and control) participants were patients post-CABG who spent more than 72 hours on mechanical ventilation. The early rehabilitation included training the patient through 6 stages of mobility that start with the ability to raise the head and end with the ability to walk around the bed, while the control group received their phase I CR on the ward. The results showed that the intervention group when compared to the control group, had significantly decreased the mean duration of mechanical ventilation (8.1, SD = 3.3 days vs 13.9, SD = 4.1 days, p-value < 0.01), shorted ICU stay mean (11.7, SD = 3.2 days vs 18.3, SD = 4.2 days, p-value < 0.01), and shorted hospital stay mean (22.0, SD = 3.8 days vs 29.1, SD = 4.6 days, p-value < 0.01). The study showed that early CR is beneficial in accelerating weaning from mechanical ventilation and decreasing both ICU and hospital stays. Although there needs to be caution in extrapolating these results, this study's findings support the idea that CR may yield better outcomes when started early than when done late. Notably, this study is classified as having a high risk of bias when rated by PEDro due to failure to meet 6 criteria, including an incomparable baseline between the groups, which should be considered when using the study results.

1.7.3.2 The Effect of Early CR

This section covers the studies that explore the influence of early CR on various measured outcomes, and they are more in line with the SheppHeartCABG trial (Højskov et al., 2019).

1.7.3.2.1 The Effect of Early CR - Phase I CR (Acute Hospital Period)

In a high-quality RCT with a sample of 64 patients post-CABG, Hirschhorn et al. (2012) investigated the impact of moderate-intensity exercises early during phase I of CR. They mainly used 2 modes of exercise (walking vs cycling) and if it would improve submaximal functional capacity. They found when comparing the performance of both modes of exercise early in phase I of CR that there was a nonsignificant difference in the mean of 6MWT and the 6-min cycle assessment (cyclists: 402, SD = 93 m vs walkers: 417, SD = 86 m, p-value = 0.803), 6-min cycle work (cyclists: 15.0, SD = 6.4 kJ vs walkers: 14.0, SD = 6.3 kJ, p-value = 0.798) respectively. They also report that there were nonsignificant differences in any aspect of HRQL between the cyclists and walkers. Additionally, both groups did not significantly differ in hospital length of stay or the incidents of atrial fibrillation. Furthermore, none of the participants had sternal wound complications during the in-patient period and 6 months after discharge and nonsignificant difference in the 6-month mortality between cyclists and walkers. They concluded that the effect of early in 2 different moderate-intensity exercises is similar in improving functional capacity as well as safe (Hirschhorn et al., 2012). However, these findings should be examined in the light that women were underrepresented in the study as they made up only 11.0% of the participants, although it was conducted in the modern era of cardiology which would affect its generalizability. Also, the outcomes measurements, 6MWT and the 6-min cycle assessment were carried out before the hospital discharge, and since the median hospital length of stay was 7 days, it may be a short period to detect significant changes.

An earlier high-quality RCT by Hirschhorn et al. (2008), with a sample of 93 patients post-CABG, tested the effect of early supervised extensive walking exercise (with and without breathing exercises) during phase I of CR. They compared the 6MWT distance at hospital discharge for the walking group, walking/breathing group, and the usual care

group. The walking distance means for the usual care group was significantly lower (377, SD = 90 m) than the other 2 groups, walking and walking/breathing (444, SD = 84 m) and (431, SD = 98 m), respectively. However, there were nonsignificant differences between the 3 groups for the 6MWT distance at a 4-week follow-up with no exercise supervision. Furthermore, adding intensive walking during phase I of CR did not significantly differ for pulmonary function measured through respiratory vital capacity or HRQL (Hirschhorn et al., 2008). Both this study and (Hirschhorn et al., 2012) showed that moderate-intensity exercises early during phase I of CR are effective with significant impact when measured during discharge; however, this study showed that patients need to continue their rehabilitation programme afterwards (maybe starting up taking core CR) or their functional capacity improvement will not be sustained. Furthermore, the generalizability of their findings can be questioned as male patients made up 87.0% of the sample, which does not reflect the usual percentage of men to women post-CABG and the sex-specific changes.

The RCT by Højskov et al. (2019) is a moderate-quality trial; they conducted an early comprehensive phase I CR programme, which included physical and psycho-educational treatment for the intervention group that continued up to 4 weeks postoperatively compared to the control group who had received usual care. They recruited and randomised 326 patients into the 2 groups, while 66.6% (214 patients) completed the trial. As with other RCTs, the proportion of both gender among the participant do favour the men and represent them more than they are in real life, as they were making 87.0% in the intervention group and 86.0% in the control group. Moreover, the study failed to describe the physical exercises used, including the intensity and frequencies, which did not allow the examination of the suitability of the exercise protocol to meet the study aims. In addition, when reporting the baseline measurement, there was no mention of the baseline values for the primary outcome (6MWT) or secondary outcomes to showcase if there was

any difference between the groups before the start of the study. Similar to (Hirschhorn et al., 2008), they report a nonsignificant difference in 6MWT distance at the 4-week follow-up between both groups, 16.2 m (95% CI: 13.0, 45.4 m, p-value = 0.27), which could be due to the poor adherence to the exercise programme as 54.0% of the participants performed less than 50.0% of the sessions, or it could be that 4 weeks is insufficient time to bring about a change in physical fitness. Also, there was a nonsignificant difference in HRQL scores between the groups, while for psychological health, the Hospital Anxiety and Depression Scale (HADS) was only partly effective pre and post (for depression) but was not significant as part of the regression analysis when only those that completed CR were included. On the other hand, conducting a comparison between the completers only and all the control groups may not be an accurate analysis because using a complier average causal effect analysis would give a robust estimate of the intervention effect (McGregor et al., 2020). On the other hand, a low-quality RCT (Borzou et al., 2018) looked into the effect of intensive phase I CR (30 patients post-CABG) versus the control group (usual care and 30 patients post-CABG) on general and exercised self-efficacy and subsequently behaviour changes. The study found that the 2 groups had a nonsignificant difference before the CR for both types of self-efficacy, but the intervention group had significant improvement when measured at discharge and follow-up after a month.

Functional capacity and respiratory health were also tested by a moderate-quality RCT comparing the intensive phase I CR programme with physical and respiratory exercises for the intervention group against the usual care for the control group (Stein et al., 2009). The study participants were patients post-CABG, with half the patients (age mean = 64, SD = 7 years) allocated to the intervention group and the other half (age mean = 63, SD = 6 years) to the control group. Again, in line with Hirschhorn et al. (2008), measuring the submaximal functional capacity using 6MWT at day 7 postoperative showed that the intervention group had significantly better performance than the control group. While for

maximal functional capacity VO_{2peak} at 30-day post-CABG measured using incremental cardiopulmonary exercise testing on a treadmill, there was a significant difference of 14 (SD = 0.8) mL/kg/min for the control group and 18 (SD = 3) mL/kg/min for the intervention group, p-value < 0.05. On day 7, respiratory muscle strength and pulmonary function were reduced for both groups and significantly recovered for the intervention group at 30-day postoperative.

However, using 6MWT as submaximal functional capacity maybe not be an accurate test. In a study by Snader et al. (1997), the metabolic equivalents (METs) were measured during a treadmill test to estimate the functional capacity of 3,400 men and women patients with no cardiac conditions. They classified the patients according to gender and age group, and they reported that for average women ≥ 60 years old, their METs would be from 6-8 and 7–9.5 METS for average men from the same age group (Snader et al., 1997). In another study by Gee et al. (2014), the METs level for cardiac patients before CR was 7.02 METs for women and 8.93 METs for men. According to the 2011 Compendium of Physical Activities, the METs required for walking moderate pace as it is during 6MWT is 3.5 METs, while the effort needed by a patient with a fitness level of 6 METs to perform a walking test would be 3.5/6 * 100 = 60.0% which is below what consider a submaximal functional capacity test.

 A low-quality RCT by Ximenes et al.(2015) reported that adding resistance exercise to the intervention group in phase I of CR did not prevent the pulmonary function from decreasing when measured at hospital discharge for both the intervention group and control group, while the assessing submaximal functional capacity by comparing mean predicted distance of 6MWT, the control was lower at hospital discharge compared to preoperatively (59.2, SD = 11.1% vs 50.6, SD = 9.9%, p-value < 0.016) and a nonsignificant difference for the intervention group (54.1, SD = 22.7% vs 52.5, SD = 15.5%, p-value = 0.42). Moderate quality RCT by van der Peijl et al. (2004) compared

the effectiveness of high-intensity phase I CR (the intervention group = 134 patients post-CABG) against low intensity (the control group = 112 patients post-CABG). They report that the intervention group achieved the main functional steps of sitting in a chair, walking in the room, walking in the ward, and group exercise therapy in a more timely manner. In a low-quality quasi-experimental study by Thapa and Pattanshetty (2016), they reported that a low-intensity exercise in the form of chair exercise would yield a significant difference for 6MWT at hospital discharge compared to baseline (189.08, SD = 122.15 m vs 97.22, SD = 76.51 m, p-value < 0.001).

A high-quality quasi-experimental study by Mendes et al. (2011) aimed to examine the effect of early phase I CR on cardiac autonomic by comparing heart rate variability of 2 groups, 23 patients post-CABG with normal left ventricular function and 21 patients post-CABG with a reduced left ventricular function where they report. They report that heart rate variability significantly improved for patients with reduced left ventricular function than those with normal left ventricular function. A similar study was conducted by a moderate-quality RCT by Mendes et al. (2010); however, they compared an intervention group (24 patients post-CABG) that received exercise based on early phase I CR and a control group (23 patients post-CABG) that received breathing and airway clearness exercises phase I CR. They reported that heart rate variability significantly improved for patients in the intervention group compared to patients in the control group.

Two low-quality RCTs investigated the effect of supplementing conventional phase I CR with an additional form of therapeutic intervention or exercise. Ratajska et al. (2020) aimed to study the effect of usual CR phase I supplemented with myofascial release techniques on breathing, physical fitness, pain, and fatigue level. They recruited 80 patients post-CABG or following off-pump CABG surgery, with 40 patients in the control group (phase I CR) and 40 in the study group (phase I CR with added myofascial release). Phase I CR started from the first-day post-op for all participants, while the myofascial

release started third to sixth post-op for a study group. All participants showed positive responses; however, the study group had significant improvement, compared to the control group, in pain and fatigue levels (on the fourth and sixth-day post-op) and breathing difficulties and physical fitness (on and sixth-day post-op). The results showed the benefit of early intervention in improving respiratory fitness, pain and fatigue for patients post-coronary revascularisation (Ratajska et al., 2020). The second study was by Faizan Hamid et al. (2022); they examined the effect of adding lower limb exercises to phase I CR on quality-of-life (SF-36), functional independence measure, formative self-efficacy questionnaire, ejection fraction and arterial blood gasses. The trial recruited patients post-CABG with 27 patients in the control group (phase I CR) and 27 patients in the study group (phase I CR with lower limb exercises using a paddler) that continued for 7 days post-op with baseline measured on the first day and outcomes at the seventh day. All outcomes were observed to improve for all participants in both groups, except for ejection fraction (no change on the seventh day than baseline), while self-efficacy on the seventh day has improved, but there are no significant differences between groups. On the other hand, the improvement in QOL, functional independence, and arterial blood gasses were all significantly more significant in the study group than in the control group. The results suggest that lower limb exercises during early phase I CR would enhance the QOL, functional independence and arterial blood gasses.

1.7.3.2.2 The Effect of Early CR - Core CR Phase

Two moderate-quality RCTs tested core CR's effectiveness when conducted earlier than 6 weeks post-CABG (Tsai, Lin and Wu, 2005; Plüss et al., 2008). The trial by Tsai et al. (2005) tested for the effect on the recovery of heart rate over 1 min as an indicator for mortality. They recruited 30 patients post-CABG in the intervention group who received early core CR and 30 patients post-CABG in the control group without. They found that after 12 weeks of follow-up, the recovery of heart rate over 1 min for the intervention

group was significantly higher than the control group (16.38, SD = 6.32 bpm vs 11.38, SD = 4.81 bpm, p-value < 0.05). Plüss et al. (2008) is a trial with 127 patients post-CABG (and 97 patients post-AMI) as their sample. The control group carried out core CR (the usual care) that included an exercise programme, education session, a heart school and outpatient clinic visits; this group were compared to the intervention group that included core CR (the usual care) in addition to stress management intervention, a 5-day stay at the patient hotel and dietary counselling and healthy cooking. Since the intervention for both groups was similar, both groups showed improvement in exercise performances parameter, coronary heart disease inflammatory biomarkers, C-reactive protein and fibrinogen, and cardiac risk factors of high total cholesterol and LDL cholesterol, with nonsignificant differences between the groups. This study reported its outcomes for all participants but gave only separate measurements when it came to blood pressure, as the systolic blood pressure had increased in both groups, which contradicts the expectation of CR to reduce systolic blood pressure (van Halewijn et al., 2017). Patients post-AMI had experienced an increase in systolic blood pressure after 1 year compared to baseline for both groups; intervention group (136, SD = 25 mmHg vs 124, SD = 18 mmHg; p-value< 0.001), control group (141, SD = 28 mmHg vs 128, SD = 22 mmHg; p-value< 0.001). Similarly, patients post-CABG had an increase in systolic blood pressure for both intervention and control groups after 1 year compared to baseline (136, SD = 21 mmHg vs 142, SD = 22 mmHg; p-value < 0.001); and (138, SD = 20 mmHg vs 143, SD = 21 mmHg; p-value < 0.046) and the authors of the study could not explain the increase in systolic blood pressure.

In a high-quality quasi-experimental study by Nishitani et al. (2013), they investigated the changes seen following CR exercise training in muscle mass, muscle strength of the handgrip and thigh muscles, and exercise tolerance for 78 patients post-CABG with diabetes mellitus (37 in the DM group) compared to patients post-CABG with no diabetes

mellitus (41 in the no-DM group). At the baseline measurements (pre-CR), there was a significant decrease in knees extensors strength and exercise tolerance in the DM group compared to the no-DM group, and after CR, both groups had a significant increase in exercise tolerance and muscle strength. However, the authors failed to mention the type of equipment or protocol used for the handgrip testing considering it may affect the reliability of the results (Roberts et al., 2011). Also, when describing the muscle strengthening exercises part of the intervention, the authors describe what is considered to be callisthenics that involve performing exercises against the bodyweight resistance at different speeds without using tools or apparatus. However, this form of exercise plays no part in improving isokinetic peak torques, measured by an isokinetic dynamometer, as it is a test done at constant velocity throughout the full range of movement, which would show the authors' had inappropriate assessment selection. In other words, the selected assessment is a highly specialist exercise measure with limited generalisability to broader populations; as such, the assessment and findings should be taken with caution when compared against other literature.

The study found that muscle mass was significantly improved in the no-DM group post-CR. Also, it reported a correlation between muscle strength and glycosylated haemoglobin in patients having CR after CABG and showed the influence of patients' comorbidity profiles and assessment on CR outcomes. However, an exanimation of the correlations' coefficient of determination R^2 for the knee muscle strength change with the muscle mass of mid-upper change (r = 0.47, p-value < 0.005) would be $R^2 = 0.22$, and with the glycosylated haemoglobin change (r = - 0.41, p-value < 0.05) is $R^2 = 0.18$. This means that only 22.0% of the variance in the knee muscle strength change is accounted for by muscle mass of mid-upper change, and 18.0% is counted for by the glycosylated haemoglobin change, which would represent poor correlations (Schober, Boer and Schwarte, 2018; Heyken et al., 2021).

In a moderate-quality quasi-experimental study by Massaro et al. (2014), 60 patients post-CABG (no previous diagnosis of diabetes) underwent early core CR for 4 weeks in the hospital and then 3 months at the outpatient clinic. All patients were tested for oral glucose tolerance at baseline, where 28.3% had normal glucose tolerance, 41.6% had impaired glucose tolerance, and 30.1% had type 2 diabetes mellitus. Post-CR programme, the number of patients with type 2 diabetes mellitus was significantly decreased, and the number of normal glucose tolerance patients significantly increased. Additionally, at baseline, type 2 diabetes mellitus patients and impaired glucose tolerance patients showed worse 6MWT performances than normal glucose tolerance patients but had a similar improvement after 4 weeks of training.

Research by Szczepanska-Gieracha et al. (2012) is a moderate-quality quasi-experimental study investigating the association between early core CR and physical capacity and psychological health for 50 patients post-CABG. They reported significant improvement in the measurements, for instance, the lower pulse rate at the peak of endurance training, lower levels of exertion, depression, anxiety, and acceptance of illness for patients who were not classified as depressed or had a high level of anxiety. Patients in the depressed group had significantly improved pulse rates at the peak of endurance training, depression, and anxiety levels. In contrast, the group with a high level of anxiety group had significant improvement in pulse rate at the peak of endurance training, the level of depression and acceptance of illness. Another research (Socha, Wronecki and Sobiech, 2017), a moderate-quality quasi-experimental study with a sample size of 65 patients, aimed to assess early core CR's influence on improving body composition parameters. For all the men (N = 44) and women (N = 21) aged 50-65 years, there were significant improvements in BMI, fatty tissue, fat-free mass, total body water and body cell mass (not for women), while only males older than 65 years had significant improvement in BMI. With a small sample size caveat, this study showed that falling into a specific age

group or being of a particular gender is associated with CR outcomes. The impact of early core CR on cardiovascular events (requiring repeat coronary revascularisation, acute MI, and death) was the topic of study after a 2-years follow-up (Hansen et al., 2009) and after a 5-year follow-up by Doimo et al. (2019). In a quasi-experimental study by Hansen et al. (2009) with moderate quality with a sample of 238 patients post-CABG, 439 post-PCI patients, and an intervention group with 3-months core CR that started 1 to 2 weeks from discharge and a control group with no core CR. The patients post-CABG were significantly lower in the intervention group compared to the control group, (4.7% vs 14.0%) for total cardiovascular events, (0.0% vs 3.2%) acute myocardial infarction and (0.7% vs 5.4%) death (p-value< 0.05). A high-quality cohort study by Doimo et al. (2019) was conducted with a population of 353 post-CABG, 378 post-ST-elevation myocardial infarction, 265 post-non-ST-elevation myocardial infarction and 284 patients post-PCI. The researchers compared group 1: patients who attended an early core CR programme within 2 weeks post-discharge, and group 2, patients discharged without any programme of core CR. The results showed that participation in the CR programme was associated with lower cardiovascular events; additionally, they showed low CR starting, with 117 patients post-CABG participating in CR and 108 patients not participating in CR.

In a high-quality cohort study, they aimed to examine the effect of core CR on exercise capacity and long-term prognosis in patients post-CABG in Japan (Origuchi et al., 2020). They compared the performance of 240 patients, active participants who underwent a CR that started 2-3 weeks post-operation and lasted from 3 to 5 months, to not active 106 patients who did not participate in CR. Both VO_{2peak} and anaerobic threshold were measured via cardiopulmonary exercise testing post-CABG both early (2–3 weeks) and late 3–6 months. Each group showed a significant improvement in late measurements from early measurements; for the active group, the VO_{2peak} increased from 17.0, SD = 4.3 to 20.9, SD = 4.6 mL/kg/min, and anaerobic threshold increased from 10.7, SD = 2.4 to

12.3, SD = 2.4 mL/kg/min and non-active group VO_{2peak} increased from 17.1, SD = 4.8 to 20.1, SD = 5.6 mL/kg/min and anaerobic threshold increased from 10.6, SD = 2.2 to 11.6, SD = 2.4 mL/kg/min. However, when comparing the percentage of improvement, the active group showed a significant increase compared to the non-active group. Also, the long-term prognosis (major adverse cardiac events, all-cause rehospitalisation, rehospitalisation for cardiac reasons, and coronary events requiring hospitalisation) were significantly better for the patients in the inactive group. This means that early CR participation would lead to favourable CR outcomes and improve the survival chances for patients post-CABG.

A lower-quality RCT (as apprised by KA) done by Skomudek, Waz and Rozek-Piechura (2019) aimed to compare the effect of an intensive 4-week CR and less intensive 8-week CR on patients post-CABG with saphenous vein grafting. They recruited 47 patients in group 1 (4 weeks CR) and 14 in group 2 (8 weeks CR), 21–24 days post-operation. The lower limb average temperature showed that the operated leg measurements in group 2 were significantly lower in post-CR than pre-CR. Also, for post-CR operated leg measurements in group 2, venous pump power increased significantly. Isokinetic limb testing showed both groups benefited in increasing the muscle function of the operating limb to the non-operating limb level, but group 1 showed more nonsignificant differences between the 2 lower limb measurements. While prolonged CR with lower intensity was more effective in enhancing the lower limb temperature distribution and hemodynamics, a short and intensive CR was more influential in improving lower limb muscle function (Skomudek, Waz and Rozek-Piechura, 2019).

1.7.3.3 Factors Associated With CR Utilization From the Literature Review

Examining the findings of the literature review, it was noticed that while longer waiting time was found to be associated with underutilising and decreased improvement in CR

outcomes, there were other factors found to influence prolonged wait times, i.e., females, older age, being employed, less social support, longer drive time to CR, lower socioeconomic status, higher systolic blood pressure, abdominal obesity, being a smoker; heart failure, diabetes mellitus, MI, cardiac arrest, cardiomyopathy, stroke, post-valve surgery, anxiety and depression (Fell, Dale and Doherty, 2016; Marzolini et al., 2015; Szczepanska-Gieracha et al., 2012).

1.7.4 Conclusion

The findings of this systematic search of the literature combined with critical appraisal showed that only 27 studies had investigated the influence of waiting time, with only 5 studies comparing early CR vs late CR. Regarding quality, there were 8 high-quality studies, 13 moderate quality and only 6 studies with low quality. These studies show that waiting time correlates with utilising CR and specific patients' demographic characteristics and clinical profiles such as age, gender, and commodities. Furthermore, some studies showed an association between waiting time and various measured outcomes, whether physical, psychological or risk factors. Furthermore, when done early, it is shown that CR was considered safe since it was associated with decreased adverse cardiac events and death. So, through this literature review, this thesis has identified the gap in the research and used this body of work to inform this study methodology and assist with our future interpretation of results.

CHAPTER 2 Methodology

This chapter aims to provide a rationale for the research design, describe the data source, clarify the ethical aspects, and present the statistical methods used. The research for this thesis was conducted using a quantitative approach, and this is based on the research question, aims, objectives and the nature of the data. The following chapters, 3 to 5, through adopting the observational study methodology, analysed the existing source of data collected routinely by NACR. The top-level sample for this study is adult (18 years or older) male and female patients who underwent median sternotomy surgeries in the UK from 2013 to 2019.

2.1 Research Design

Research design is "the plan that provides the logical structure that guides the investigator to address research problems and answer research questions" (Bruce R. DeForge, 2012). Therefore, it is essential to choose the appropriate design to ensure the research is carried out to the utmost quality with interpretable results (Thiese, 2014). In health research, 2 common types of design are used: experimental and observational. During experimental research, the investigator controls the exposure to the participants, and they evaluate the introduced intervention (Chidambaram and Josephson, 2019). Experimental research can be classified according to if research has a control group; it would be either an uncontrolled or a controlled trial. In addition, the controlled trial would be categorised into randomised control trials (if the participants were randomly allocated to the groups) or non-randomised control trials with no randomisation (Song and Chung, 2010).

On the other hand, during observational research, the investigator does not intervene and, as the name implies, observes the relationship between different factors and outcomes (Carlson and Morrison, 2009). Observational research can be subclassified into several designs, such as case-control, cross-sectional, or cohort studies. Cohort design "*involves*

identifying study participants based on their exposure status and either following them

through time to identify which participants develop the outcome(s) of interest"

(prospective), "or look back at data that were created in the past, prior to the

development of the outcome" (retrospective) (Thiese, 2014).

The most appropriate research design to address this thesis research questions was a retrospective cohort observational research design utilising routine clinical practice data held by the NACR. This allowed for examining the relationship and the level of association between waiting time and CR starting, completing, and outcomes for patients post median sternotomy surgeries through utilising data obtained from NACR. There are several advantages to using observational study in general and the data held by the NACR in particular. These include processing, managing and analysing such large-scale data; this improves the researcher's analytical skills and experience. In addition, it would provide a real insight into the CR in the UK and the management of patients post-CABG, post-cardiac valve surgeries and both surgeries combined from a service level and patient characteristics perspective. Furthermore, the 'real world' and generalisability aspect of the data can be translated to local and national services, as evidenced by the use of NACR studies to influence policies and practices exemplified in the REF 2021 impact case study (Doherty et al., 2021). Finally, it is beneficial for making a comparison with recent studies, in addition to discerning the association between waiting time (early vs late) and starting, completing, and outcomes by exploring relative patients and service level variables in the NACR data. However, this type of design has some issues that require attention if the study is to be robust; these include missing data and accounting for confounding variables such as missing data that could be due to incomplete information caused by a no response or absence of participants, or outliers that may result from the incorrect response from the patient or a data entry error. Fortunately, there are several methods to handle missing data, such as complete case analysis or imputation analysis

(Kwak and Kim, 2017). In addition, accounting for potential confounding variables (e.g., gender, ethnicity) that may influence the outcome in respect of waiting time is achieved through the use of regression analysis, which allows the analysis to account for variables identified by the researcher through the thesis literature review.

The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) is a guideline used to report observational research and ensure that all the presented information is transparent and adequate, which was used for chapters 3-5. The STROBE consists of 22 items to facilitate a standardised reporting for all the manuscript sections, i.e., title, abstract, introduction, methods, results, and discussion (von Elm et al., 2014).

2.1.1 Research Design Selection

In 2018 when this thesis commenced, there was a large volume of high-quality, robust RCTs according to the systematic reviews and meta-analysis studies by Anderson et al., 2016a, Francis et al., 2019 and van Halewijn et al., 2017 as they analysed 63 RCTs, 49 RCTs and 18 RCTs, respectively. Further, there were 2 specific studies about waiting time, the SheppHeartCABG and the SCAR, which tried using the randomised control trial design and methodology to conclude on waiting time and patients following open-heart surgery (Højskov et al., 2017; Ennis et al., 2018). Meanwhile, this thesis aims to understand the role of waiting time in real-world settings and use data representative of patients with different demographic and health profiles. So, in addition to the findings of the trials SheppHeartCABG and SCAR, this thesis would add the final part of the puzzle of starting CR early vs late.

There is a traditional hierarchy of evidence (Figure 2.1(A)) expressed in the form of a pyramid that is used to rank studies' quality and reliability based on their methodology, which puts systematic review and meta-analysis at the top, then RCT, cohort studies, case-control studies, and case reports at the bottom (Murad et al., 2016). A new evidence pyramid (Figure 2.1(B)) was introduced in a perspective article in 2016 by Murad et al.,

where the straight lines that separated different research designs were changed to wavy lines indicating variability (Murad et al., 2016). They were advocating that the research design solely should not indicate the superiority of a particular study design over another, as inadequately conducted RCTs may be inferior to a cohort study with a robust methodology.
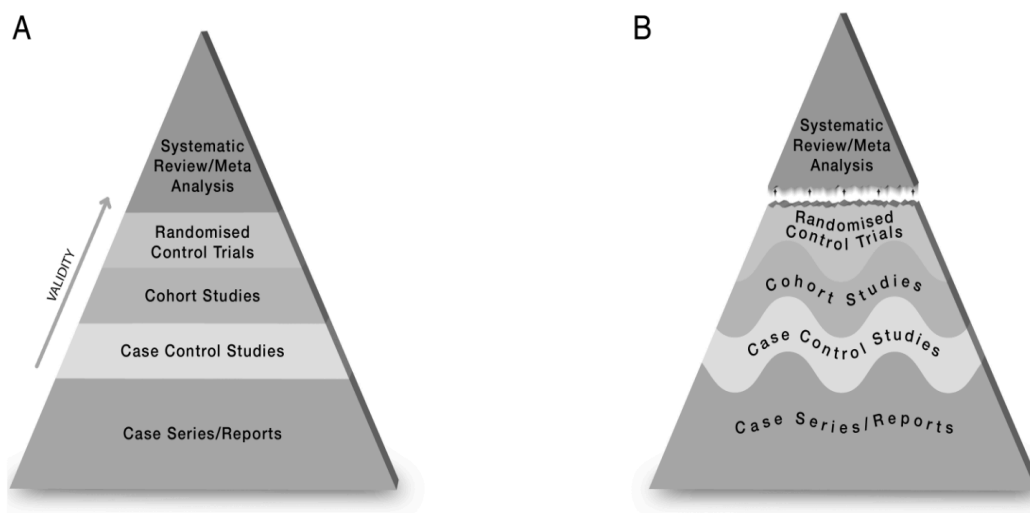
Figure 2.1 The Proposed New Evidence-Based Medicine Pyramid. (A) The Traditional Pyramid (B) Revising The Pyramid.
Adapted by permission from BMJ Publishing Group Limited. [New evidence pyramid, Murad et al., 21, 125-127, 2016].

The nature of the randomisation gives several advantages to the study by reducing selection and allocation bias and the confounding effect, also improving comparability between groups regarding unknown and known variables (Chavez-MacGregor and Giordano, 2016; Siepmann et al., 2016). However, there are some disadvantages of RCTs, such as being costly and the sample not being representative of the population because of the criteria of inclusion and exclusion, which tend to be highly selective (Sørensen, Lash and Rothman, 2006; Frieden, 2017).

Alternatively, the observational cohort study can be used to curtail the RCT disadvantages. The observational study is where the researcher observes the effect of the intervention on the subjects in real life. In addition to the data coming from a natural

clinic setting, it has the advantage of being representative of population diversity since the study will be more inclusive of all types of patients regardless of their demographic profile, such as their age, ethnicity, or the present of comorbidities many of which can be accounted for within a regression analysis with large sample size. Also, there are the advantages of not being time and financially-consuming (Sørensen, Lash and Rothman, 2006; Carlson and Morrison, 2009; Song and Chung, 2010). This type of study is not without its challenges, as it relies on retrospective data and needs to tackle issues around missing data, both of which require significant consideration when designing the studies. However, there is a wealth of evidence and robust well-produced studies produced to date that showcase the appropriate methods, limitations of weaknesses and methods for producing high-quality evidence that this thesis has sought to help with methodological decisions at each stage of the process while shaping and conducting this thesis.

2.2 Factors Associated With CR Utilization and Outcomes

Screening the broader literature for variables associated with CR starting, completing, or outcomes in the general population of patients post cardiac conditions such as PCI have yielded two sets of variables based on whether NACR collected them. Table 2.1 lists the 20 factors available in the NACR database, such as confirmed joining date, previous CABG or previous CR and their corresponding references. While Table 2.2 lists the factors that are not collected by NACR, such as language, religion, education or/not applicable to the population in the UK, i.e. CR centre with American Association of Cardiovascular Pulmonary Rehabilitation (AACVPR) certification or insurance coverage. All the independent variables used in analyses are described in chapter 3 (starting CR), Table 3.1, chapter 4 (completing CR) Table 4.1.

Table 2.1 NACR Factors for CR Utilizing and Outcomes From Literature Screening

Independent Variables	References
Age	Sumner et al., 2016; Turk-Adawi et al., 2014; Doolan-Noble et al., 2004; van Engen-Verheul et al., 2013; Al Quait, 2018; Marzolini et al., 2008; Smith et al., 2006
Gender	Jegier et al., 2011; Shanks et al., 2007; Al Quait, 2018; Sarrafzadegan et al., 2007; Yohannes et al., 2007
Ethnicity	Al Quait, 2018; Prince et al., 2014; Zhang et al., 2017
Partnership status	Al Quait, 2018; Sumner et al., 2016; Marzolini et al., 2008; Smith et al., 2006
SES	Al Quait, 2018; Doolan-Noble et al., 2004; Dankner et al., 2015
Previous CR	Al Quait, 2018; Doolan-Noble et al., 2004
Treatment type	Al Quait, 2018; Ratchford et al., 2004; van Engen-Verheul et al., 2013; Sumner et al., 2016; Marzolini et al., 2008
Comorbidities	Al Quait, 2018; Sumner et al., 2016; Marzolini et al., 2008; Worcester et al., 2004; Turk-Adawi et al., 2014; Sarrafzadegan et al., 2007; McGrady et al., 2009
Previous CABG	Sumner et al., 2016; Turk-Adawi et al., 2014.
A diagnosis of ≥ 2 cardiac event	Ratchford et al., 2004
Hospital length of stay	Al Quait, 2018; Jegier et al., 2011; Martin et al., 2012
Confirmed joining date	Al Quait, 2018
Social support	Al Quait, 2018
Employment	Al Quait, 2018; Sumner et al., 2016; Worcester et al., 2004
BMI	Al Quait, 2018; Dankner et al., 2015; Marzolini et al., 2008; Sarrafzadegan et al., 2007
Physical activity	Al Quait, 2018; Dankner et al., 2015; Worcester et al., 2004
Smoking	Al Quait, 2018; Ratchford et al., 2004; Sarrafzadegan et al., 2007; Turk-Adawi et al., 2014; Worcester et al., 2004.
Alcohol consumption	Al Quait, 2018
CR delivery Factors**	Al Quait, 2018
Multidisciplinary team and BACPR certified programme	Included to factor in the variation for different CR programmes

*Angina, diabetes mellitus, hypertension, anxiety, depression, family history of CVD, hyperlipidaemia, number of comorbidities. **CR delivery mode, referral source and referring health professional
CR: cardiac rehabilitation. CABG: coronary artery bypass grafting. CVD: cardiovascular disease. SES: socioeconomic status.

Table 2.2 Independent Factors Mentioned in the Literature and Not Collected by NACR

Independent Factors Mentioned in the Literature and Not Collected by NACR	
Language	Transportation
Religion	Settlement location
A history of chronic kidney disease	Referral type
Catecholamine use	Admission to a large hospital
cardioprotective medication use	The strength of physician's recommendation
Disease severity (ejection fraction)	The frequency of CR promotion to patients and health care providers
Locomotor apparatus diseases	CR centre with American Association of Cardiovascular Pulmonary Rehabilitation (AACVPR) certification
Psychiatric diseases	Insurance coverage
High self-efficacy expectation	Travel time to CR centre
Education	

CR: cardiac rehabilitation. NACR: National Audit of Cardiac Rehabilitation

2.3 Data Source

The NACR is an audit that operates with and is funded by BHF, collecting and analysing the CR programmes data in the UK with the purpose of optimising the quality of cardiovascular health services for CVD patients in the UK. The NACR mission statement is "The National Audit of Cardiac Rehabilitation (NACR) is a British Heart Foundation (BHF) strategic project supporting cardiovascular prevention and rehabilitation services to achieve the best possible outcomes for people with cardiovascular disease irrespective of where they live" (NACR, 2018).

Since the data is collected by the NACR for their own objectives, it would be classified as secondary data (Windle, 2010). One advantage of secondary data is that it is readily available; therefore, resources can be saved since there will be no need to obtain funding or collect the data, but it does require significant data preparation, to meet the requirements for robust regression analysis. Also, since the NACR uses standardised questionnaires and measurements and as the data set is consistently analysed and errors

addressed, this helps ensure quality data is optimal. Furthermore, the scale of secondary data usually exceeds any primary data source, which could also be beneficial to the validity of the statistical analysis, especially regression analysis that seeks to account for potential confounding variables. Since 2020 NICE has incorporated real-world evidence (observational studies) as part of its clinical evidence guidelines encouraging the use of registry-based studies. This has subsequently led to the release of the NICE real-world evidence framework in June 2022, which reiterates the importance of robust observational data in research that can help inform clinical practice (NICE, 2022).
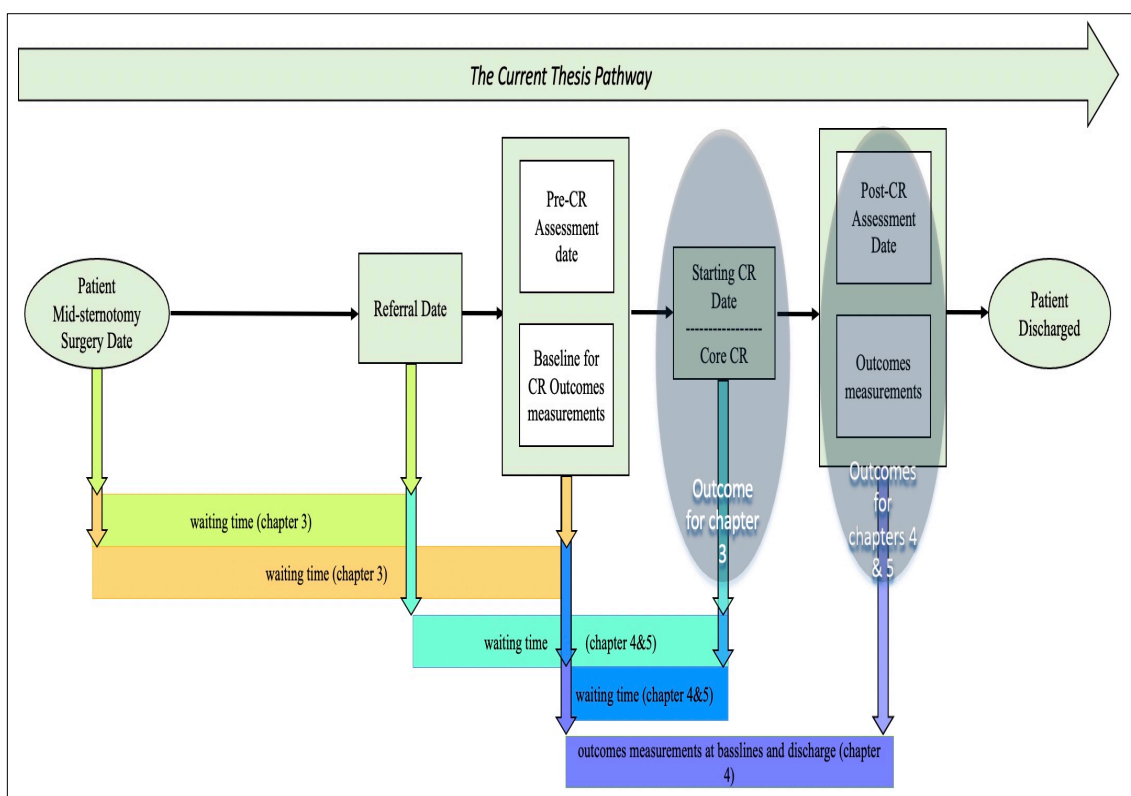
Figure 2.2 The Current Thesis Pathway Based on the Stages of the CR Pathway in the UK Setting

CR: cardiac rehabilitation.

The Department of Health Commissioning Guide Six-Stage Patient Pathway of Care, as illustrated in Figure 1.1, was adapted in Figure 2.2 to visualise all the crucial stages that would provide meaningful information in the formalisation of the methodology, whether it is a specific date used to calculate a period of time, which would be explained in each corresponding chapter, or the stages where assessments were carried out. Figure 2.2 also

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shows the phases where the thesis outcomes fit, i.e., the outcome for the regression analysis in chapter 3, which is starting CR, then the outcome for the regression analysis in chapter 4, which is completing CR and the outcomes for the regression analyses in chapter 5, which are the measurement at post-CR assessment for cardiovascular risk factors, psychological health, and physical fitness.

2.3.1 Data Cleaning and Outliers

The NACR team routinely runs data cleaning and validation for its different variables such as weight, height, and body mass index (BMI) by examining for extreme values and values out of the set range; for example, for weight, the acceptable range would be between 30 and 300 kg and other than that it would be invalid (NACR Data Dictionary at http://www.cardiacrehabilitation.org.uk). However, since the new calculated variables of different waiting times were introduced, there was a need to address how the invalid data would be dealt with.

NACR include several variables that document the dates for specific events for all the patients, such as the surgery date or the date of post-CABG assessment. Due to data input variation by clinical teams, there was a need to operationally define CR wait times and CR duration using validation rules, thus enabling consistency in calculated time periods. The validation rules rejected the finishing date if it occurred before the starting date or if there were more than 365 days between the two dates.

2.4 The Ethics Approval

The Health Research Authority's Confidentiality Advisory Group under Section 251 of the NHS Act 2006 has authorised NHS Digital, and by extension NACR, to not seek patients' explicit permission to use their data. During hospital admission for patients with cardiac events or post-cardiac operations, it is highly challenging for the staff to obtain the patients' consent to collect and utilise their data for any cardiac-related national audits.

That is why the NHS established an "exemption from consent"' process, which means there is no need to seek the patient's explicit consent for their data (whether personal or medical) to be entered into NHS systems. Through face-to-face communication and the audit assessment questionnaires, the patients are provided with all the information needed about the audit, such as its purpose, how their data will be collected and utilised and who has access to it. All patients are given the option to opt out without their treatment being affected as per NHS Digital and NACR protocols (NACR, 2018). In addition, the NACR and this PhD study would only have access to pseudo-anonymised data from the NACR database without patients identifications.

2.5 Data Analysis

In the context of this PhD, data analysis is primarily quantitative and underpinned by a process and exploration of data, which, combined with robust statistical analysis, can support inferences that may contribute to answering the research question (Layder, 2013). Quantitative data is the result of measurements in the form of numbers, the quality of which determines the type of data analysis and statistical methods to be used in research (Singh, 2007). When analysing quantitative data, there are 2 statistical approaches: descriptive and inferential statistics (Ali and Bhaskar, 2016). Descriptive statistics can be used to describe the research population demographics or outcomes using either a single absolute measure which can be accomplished, for example, through measurements of the frequency of an event within categorical variables or measurements of central tendency and variation for continuous variables (e.g., mean, median, standard deviation) (Mishra et al., 2019). Inferential statistics refers to using statistical methods to draw conclusions about a research population (Marshall and Jonker, 2011). It can be used to examine differences or test for associations, which in turn is dependent on the types of data (categorical or continuous), the number of groups (2 or more), and if they are paired or independent of each other (Simpson, 2015). Therefore, 4 types of tests were used in this

thesis: independent *t*-test, chi-square test of independence, and multivariable logistic and linear regression.

The independent t-test (*t*) compares the difference between the means of unrelated groups (Kim, 2015), which for example, is used in Chapters 3-4. It tests for means differences in age between the 2 different groups of patients. A chi-square test of independence (χ^2) compares the frequencies between 2 or more categorical groups (Franke, Ho and Christie, 2012). The corresponding degrees of freedom (df) were reported between parentheses. In chapters 3-5, it was used to compare between variables with 2 or more categories, e.g., compare between binary variables of waiting time with and starting CR. Regression analysis, more specifically multiple regression, is used to measure the level of associations between several independent (explanatory) variables and one outcome variable (Lewis, 2007). All the statistical tests would be considered significant if the p-value < 0.05. It would be adjusted for multiple chi-square tests by using Bonferroni correction, where the new p-value would be calculated by dividing 0.05 over the number of tests, e.g., 0.05 / 20 = 0.003 a test would be deemed significant if the p-value < 0.003 (Sinclair, Taylor and Hobbs, 2013). All the analyses were performed using IBM SPSS Statistics for Windows, Version 27.0 (Armonk, NY: IBM Corp).

2.5.1 Logistic Regression

Measuring the level of association between multiple variables and a binary outcome requires the use of logistic regression. When building the analysis model, a hierarchical method was used, i.e., the independent variables were entered in blocks based on logical reasoning, which would inform how much variance is accounted for by the variables in every step and how they are contributing to the model (Jeong and Jung, 2016). The models' blocks were assessed by comparing -2 log likelihood, Nagelkerke R^2 and overall model accuracy (Osborne, 2015). Also, the backward selection method was used, which

involved a repeated elimination of nonsignificant independent variables (p-value > 0.05) until all variables were significant (p-value < 0.05) (Chowdhury and Turin, 2020).

After creating the model and generating the analysis output, the fit, efficacy, and accuracy of the model are assessed through the following:

1) The model chi-square Goodness of Fit test: to examine the null hypothesis that any of the coefficients of independent variables equal zero; if the p-value < 0.05, that would mean that the model is significant.

2) Nagelkerke R^2: to indicate how much the outcome variability can be accounted for due to the model.

3) Hosmer-Lemeshow goodness of fit test χ^2: to examine the null hypothesis that the model is fit, which means if the p-value > 0.05, it would mean failure in rejecting the hypothesis.

4) The percentage of how much the model could correctly classify the cases. Further, evaluate the model sensitivity (i.e., the proportion of the positive outcome was correctly identified in the model) and the model specificity (i.e., the proportion of the negative outcome correctly identified in the model). Moreover, receiver-operating characteristic (ROC) analysis, which is a plot of sensitivity against 1 – specificity, analysis results must show the area under the curve (AUC) above 0.5 for the model to be considered for discrimination (Zou, O'Malley and Mauri, 2007).

After evaluating the model, examine the assumptions of the logistic regression, and they are:

1) The assumptions of the dependent variable are binary (Abonazel and Gamal Ghallab, 2018).

2) The observed data is not dependent, as when they are the results of repeated measures (Ernst and Albers, 2017).

3) Having a sufficient sample size, i.e., all the thesis analyses had to meet and exceed the recommended minimum sample size of 500 cases, allowing analysis to represent the population (Bujang et al., 2018).

4) There is no multicollinearity between the independent variables by running collinearity diagnostic statistics and examining the outcomes A) tolerance for being close to 1 than 0 and B) variance inflation factors (VIF) to be less than 10 (Midi, Sarkar and Rana, 2010).

5) Linearity in the logit which checked by creating a new variable, the log of the continuous independent variable in the analysis, then rerunning the regression, adding an interaction between the continuous independent variable and its log transformation, which, if the interaction was not significant ($p > 0.05$) mean the assumption was met (Stoltzfus, 2011).

6) The final assumption is to check that the data was without unacceptably influential values (Stoltzfus, 2011).

   a. Standardised residuals: none of the values should be more than 3.29, and the number of the residuals should not exceed 1.0% if they are more than 2.58 and 5.0% if they are more than 1.96 (Andy Field, 2018).

   b. Cook's distance shows if there is an influence of a case over the model if its value is more than 1 (Verkoeijen, Polak and Bouwmeester, 2018).

   c. DFBeta: represents the influence of a case when added or dropped on regression coefficients, and it is checked that its values are less than 1 (Verkoeijen, Polak and Bouwmeester, 2018)

   d. Leverage values: They measure the influence over regression surface by the observed values of outcome variables, and they are regarded to be highly influential if they were larger than 3 $(k + 1)/n$, where n was the

sample size, and k was the number of predictors) (Andy Field, 2018; Aguinis, Gottfredson and Joo, 2013).

The significant independent variables will be presented using the odds ratio (OR), associated confidence interval (CI), and p-value. The OR could be 1 of 3: OR = 1, which means there is no difference between the chances of the occurrence of one event compared to the other; OR > 1 is one group had higher chances of the occurrence compared to the reference group, and OR < 1 is the opposite with lower chances compared the reference group (Zou, O'Malley and Mauri, 2007). To provide a better understanding of the results, reciprocals of OR may be presented, which is 1 / OR; for example, with OR = 0.88 being interpreted as patients post-valve surgeries having lower chances by 0.88 of CR starting compared to patients post-CABG, it can also be represented as 1 / 0.88 = 1.14 and interpreted as patients post-CABG have higher chances of CR starting compared to patients post-valve surgeries by 1.14 times (Bland & Altman, 2000). Furthermore, the OR can be represented as odds percentage, where if OR > 1, it can be converted to a percentage by (OR − 1) × 100 and if OR < 1, the conversion would be by 1 − OR) × 100 (Knapp, 2018).

2.5.2 Linear Regression

The linear regression model is used to describe the association between explanatory variables and one continuous outcome. This thesis has 3 types of explanatory variables: continuous, dichotomous, and multicategorical. For the multicategorical variables to be applied to the linear regression, they are required to be coded into sets of dichotomous dummy variables that are equal to the number of categories minus 1 category, which would be the reference category, and it would be coded (0, 1) with 0 meaning the absence of the category and 1 the presence of a category (Hayes and Preacher, 2014; Darlington and Hayes, 2017). Also, the models would follow a hierarchical method, i.e., the independent variables are built into the model in blocks.

The Goodness of Fit measurements is used to evaluate the fit of the model's F test and coefficient of determination (R^2). The F test and its corresponding p-value would check if the overall model were statistically significant (Sureiman and Mangera, 2020). The coefficient of determination (R^2) estimates the degree to which the regression model explains the variation in the data (Casson and Farmer, 2014).

When conducting multiple linear regression, a set of assumptions needed to be met:

1) Linearity means a linear relationship between the model's dependent and independent variables. Testing linearity is conducted by visually inspecting a scatter plot of regression standardised residual versus regression standardised predicted and assessing that the residual data is distributed randomly around zero on the y-axis in a linear manner (Cleophas and Zwinderman, 2009).

2) Homoscedasticity (i.e., homogeneity of variance) is a term used to describe when the error variances appear to be equal over the range of independent variables. This is examined by visually inspecting the regression standardised residual versus regression standardised predicted scatter plot and ensuring that the residuals are distributed randomly with no increasing or decreasing pattern (Hair Jr. et al., 2013; Andy Field, 2018).

3) Multicollinearity describes a correlation among the independent variables of regression analysis (Kim, 2019). Multicollinearity can be detected by the variance inflation factor (VIF) measurements and its reciprocal tolerance for every independent variable if they are more than 10 or less than 0.1, respectively (Miles, 2014).

4) The normality assumption is about the residuals being distributed normally around zero (Ernst and Albers, 2017). One approach to test normality is visually inspecting the probability–probability (P–P) plot and observing if the distribution follows a straight line and is not curved (Rani Das, 2016).

5) The independent error is used to describe the uncorrelation between residuals as they are independent of each other (Andy Field, 2018). The Durbin–Watson test is used to investigate this assumption; as there is no correlation, the result should be close to 2 for it to be valid (Osborne, 2017).

6) The last assumption regarding the absence of unusual cases involves identifying cases that are outliers and had high influences or leverage on the regression disproportionately and affect the model fit; in addition, these cases could be unrepresentative of the population and decrease the sample generalizability (Aguinis, Gottfredson and Joo, 2013; Osborne, 2017).

   a. The unusual cases would be detected by inspecting the scatter plot of regression standardised residual versus regression standardised predicted and removing any case beyond $\pm$ 3 standard deviations on the Y or X axis (Aguinis, Gottfredson and Joo, 2013).

   b. Also, detecting the cases with increased leverage, there would be a high gap between them, and the cut-off point for centred leverage, which is calculated for a large sample by 2 * k/n (k = the number of independent variables, n = the number of the sample) (Aguinis, Gottfredson and Joo, 2013).

   c. An additional tool to find cases that affect the model fit is the cook's distance and inspecting values higher than 1 (Ritz and Skovgaard, 2007).

The roles of significant independent variables were expressed using an unstandardised coefficient (B), p-value and 95% CI. Unstandardised coefficient (B) represents the relationship between the independent variable and dependent variable, i.e., if B was positive, it implies that every unit increase of the independent variable would result in an increase in the dependent variable by B unit, and the positive is true if B was negative (Allen, 2017).

2.5.3 Dealing With Missing Data

Health databases are susceptible to the predicament of missing data, which is the unavailability of some information for certain observations or cases (Vogt, 2005). Since almost all statistical analyses require a complete set of cases with all values for variables to be tested, action is required to deal with the missing data by using complete cases only or replacing missing values. Complete case analysis (also called listwise or casewise deletion) involves discarding observation with any incomplete variables, and it is the default option in statistical packages (e.g., SPSS) as well as the most commonly used approach in dealing with missing data (Cook, 2021).

Missing data can be classified into 3 types missing completely at random (MCAR), missing at random (MAR), and missing not at random (MNAR). MCAR is the assumption that observed data are not systematically dissimilar to missing data; that is, the data is missing independent of the observed data (Chowdhry, Gondi and Pugh, 2021; al Shaaibi and Wesonga, 2021). MAR is the assumption that observed data are systematically dissimilar to the missing data, but it can be explained by the observed values and, that is, the data is missing dependent on the observed data (Chowdhry, Gondi and Pugh, 2021; Madley-Dowd et al., 2019). Finally, MNAR is when observed and missing data are systematically dissimilar; that is, the data is missing depending on the unobserved data (Chowdhry, Gondi and Pugh, 2021; Shaaibi and Wesonga, 2021).

Determining the missingness mechanism would require applying Missing Value Analysis (when using the SPSS package) and obtaining the result of Little's MCAR test (Alshakhs et al., 2020). The test is under the null hypothesis that the data were missing completely at random, which means if the test was nonsignificant (p> 0.05), we fail to reject the hypothesis, and the data could be MCAR (Little, 1988). There are various methods available to handle missing data, and one of them is multiple imputations (Schafer and Graham, 2002; Sterne et al., 2009). Multiple imputations involved generating several

incomplete datasets and drawing possible values from the imputed model to replace the missing data (Rezvan, Lee and Simpson, 2015). The number of imputed data sets chosen was 10 since it was reported to be sufficient (Schafer, 1999). The imputed data is recommended to be checked by comparing it to the observed data to ensure the validity of the result yielded from multiple imputations datasets (Nguyen, Carlin, and Lee, 2017). In chapter 4, there were a considerable number of pre-defined independent variables, 35 to be precise, which due to the nature of the health database, had a prevalence of incomplete cases. In the preliminary data analysis, there were 4,238 complete cases for all the variables, as opposed to 32,336 cases with the essential variables (explained more in chapter 4 (section 4.5.2). Therefore, multiple imputations were used to handle the missing data to optimise statistical inferences validity, reduce the risk of bias and improve the generalisability of the results (Kang, 2013).

CHAPTER 3 Starting CR for Post-Surgical Cardiac Rehabilitation Patients

3.1 Background

Based on the American College of Cardiology Foundation/American Heart Association Task Force on Practice guidelines, cardiac rehabilitation for patients post-CABG is recommended as a class (I) and level of evidence (A) due to the existing research and endorsement that support its benefit and based on several randomised clinical trials and meta-analyses (Hillis et al., 2012). Nevertheless, despite the strong recommendations, the number of patients post-CABG starting CR is below the recommended level (Suaya et al., 2007; Balady et al., 2011; Dalal, Doherty and Taylor, 2015; British Heart Foundation, 2019b; NHS, 2019).

Moreover, there is a delay in starting CR by 6 to 8 weeks due to guidelines issued by different cardiovascular disease societies for patients post open-heart surgeries (Piepoli et al., 2010; Royal Dutch Society for Physical Therapy, 2011; Environment et al., 2014). These guidelines are due to the nature of open-heart surgeries, which are performed by surgical incisions into the sternum medially to access the heart and its valves and coronary arteries (Drake, Vogl and Mitchell, 2009). Due to the similarity of the surgeries, these guidelines target patients post median sternotomy, i.e., post-CABG and post-valve surgeries. It was reported that patients post-valve surgeries and post-CABG had comparable characteristics (Stewart et al., 2003); also, the comparability extends to their level of physical fitness at pre-CR assessment and their improvement post-CR (Savage et al., 2015). As CR has been proven beneficial for both patients post-CABG and valve surgeries, it was also recommended for patients post-combined CABG and valve surgeries (Goel et al., 2015).

The term starting CR is used to describe whether a patient with a CR referral attends their first session on the programme (Santiago de Araújo Pio et al., 2019; British Heart Foundation (BHF) National Audit of Cardiac Rehabilitation, 2019). There are several factors that could be associated with starting CR with patients post-CABG and valve surgeries, often classified into 4 categories: socio-demographic, cardiac risk factors, lifestyle and health status and service level factors (al Quait, 2018). These factors had been the subject of investigation in several studies for mixed patient populations, i.e., a study would have patients diagnosed with CABG, AMI, and PCI. However, there are limited studies investigating CR starting and outcomes in patients post median sternotomy (e.g., post-CABG, post-valve surgeries or combined CABG and valve surgeries). These studies are 3 cohort studies conducted using populations in different countries, i.e., the United States, Canada, and the UK, and one RCT (UK); hoping this research bridges the gap between trials and clinical practice (Pack et al., 2015; Marzolini et al., 2015; Fell, Dale and Doherty, 2016; Ennis et al., 2022). Moreover, the factors associated with starting CR in the literature give a conflicting result between being predictors for starting CR or having no association with participating in CR (Resurrección et al., 2019). This study aims to determine the level of association between waiting time and CR starting for patients following CABG, post-valve surgeries and combined CABG and valve surgeries.

3.2 Study Objective

The study objective is to design, conduct, analyse and interpret the findings on waiting time based on an observational study using national audit data in patients following coronary bypass graft surgery/cardiac valve surgery/or both. The overarching research question that this chapter will address is "What factors are associated with waiting time and starting in patients following CABG, post-valve surgeries and combined CABG and valve surgeries".

The study's nondirectional (a two-tail test) hypotheses would be as follows:

The Association Between Waiting Time and Starting, Completion and Outcomes in Post-Surgical Cardiac Rehabilitation Patients.

H0 (null): Waiting time has no association with starting CR.

H1 (experimental): Waiting time has an association with starting CR.

Operational definition for this thesis: Because the sample population comes from routine clinical practice and as per national audit data reporting, all participants/ people are referred to as patients from here on in this thesis.

3.3 Methods

Although the core methodology was detailed previously, in chapter 2, this chapter refers to the unique aspects that relate to the specifics of this particular study.

3.3.1 Study Design

This study was a retrospective observational study including all the male and female adult patients (18 years and older) post-cardiac surgeries via mid-sternum, specifically CABG, cardiac valve surgery or both. This study included all cases with complete data from all the cardiac centres to minimise selection bias and ensure applicability and generalisability. Where cases were revoked, comparable demographics, e.g., age, were compared to evaluate potential selection bias. The data source is the NACR database from January 2013 to October 2019, with no exclusion criteria within this population. The reporting of this study follows the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) Statement (von Elm et al., 2014) (Appendix D).

3.3.2 Data Sources

In the UK, the BACPR require CR programmes to register and submit their data to NACR as one of the CR standards and core components (BACPR, 2017). As outlined in methodology, chapter 2, the NACR data is collected in partnership with NHS Digital and

hosted (in an anonymised format) by the University of York (NACR, 2018). The study utilised aggregate data stored in the NACR network for the last 7 years. Since 2013, the volume and quality of NACR data have improved, enabling robust analyses evidenced through over 26 peer-reviewed papers and 6 annual reports that the BHF and NHS had used to support service improvement (al Quait and Doherty, 2017; British Heart Foundation, 2019b).

3.3.3 Study Variables

A binary logistic regression was used to identify and assess the relationships between several patient/clinically related factors (as independent variables) and the patient starting CR or not (as binomial dependent variable). Since this study focused on the association between different waiting times and patients starting CR, that necessitated defining waiting times for all patients to make it possible to compare them. Therefore, since the waiting time is usually computed from the surgery date to starting CR date, this study uses the pre-CR assessment date/or referral date as a quasi-CR starting date. The other independent variables were found during the literature review to be associated with starting CR. A detailed description of the dependent and independent variables used in the study is listed in Table 3.1. In addition, the variables of partnership status, ethnicity and the number of comorbidities exist in the NACR database as categorical variables with a wide range of categories; they were recoded for several reasons, such as allowing comparison with other literature and for statistical robustness (see Table 3.2).

Table 3.1 The Study Variables – Part 1

The Variable	Description
Study Outcome	
Starting CR	Starting CR is a binary variable (No, Yes).

Table 3.1 The Study Variables – Part 1

The Variable	Description
Waiting Time	

Waiting time	Waiting time between the surgery date and the First CR assessment date/or referral date. After the removal of unusual data (less than a day or more than 365 days) then, 3 variables were created:
	1) Binary categories ($\leq$ 6 weeks WT, > 6 weeks WT).
	2) Multicategories variable with an increased 2-week interval
	   ▪ WT $\leq$ 2 weeks.
	   ▪ 2 > WT $\leq$ 4 weeks.
	   ▪ 4 > WT $\leq$ 6 weeks
	   ▪ 6 > WT $\leq$ 8 weeks.
	   ▪ WT > 8 weeks.
	3) Continuous variable (WT in weeks).

Patient Factors	
Age	A continuous variable of patient age in years
Age (Mean centring)	A continuous variable recoded the age variable (expressing patient age in years) into an age-centring variable by subtracting the population's age mean (66.93) from each patient's age.
Gender	Patient gender is binary categorisation (Male, Female).
Age*Gender	An interaction term between the continuous variable (age) and the dichotomous variable (gender).
Ethnicity	Patient ethnicity is classified into binary (white, non-white), where non-white would include the ethnic minorities, i.e., Black, Asian, or other.
Partnership status	Patient partnership status is a binary categorisation (partnered, not partnered).

Socioeconomic status (SES)	Classified into 5 categories according to the Index of Multiple Deprivation score (IMD):
	   ▪ First quintile (most deprived).
	   ▪ Second quintile.
	   ▪ Third quintile.
	   ▪ Fourth quintile.
	   ▪ Fifth quintile (least deprived).

Previous CR	Patient history of previous CR is a binary categorisation (Previous CR, No previous CR).
Cardiac-Event Factors	

Treatment type	Classified into 3 categories:
	   ▪ CABG.
	   ▪ Valve surgeries.
	   ▪ Combined CABG/valve surgeries.

Table 3.1 The Study Variables – Part 1

The Variable	Description
Angina	Patients were diagnosed with any of these comorbidities at the time of the cardiac event, which is a binary response (No, Yes).
Diabetes mellitus	
Hypertension	
Anxiety	
Depression	
Family history of CVD	
Hyperlipidaemia	
Number of comorbidities	Classified into 3 categories: ▪ No comorbidity. ▪ 1-2 comorbidities. ▪ ≥ 3 comorbidities.
Previous CABG	Patient history of previous CABG is a binary categorisation (No, Yes).
A diagnosis of ≥ 2 cardiac events	This variable is classified into 4 categories of the patient having one or more of the following cardiac events (CABG, valve surgeries, AMI, PCI) ▪ CABG or/and valve surgeries. ▪ CABG or/and valve surgeries + AMI. ▪ CABG or/and valve surgeries + PCI. ▪ CABG or/and valve surgeries + AMI/PCI.
Previous cardiac events	Having a prior diagnosis for any of the following conditions is classified into a is a binary variable (No, Yes): MI, cardiac arrest, left ventricular assist device, ACS, angina, implantable cardioverter-defibrillator, CABG, other surgery, congenital heart defect, coronary angioplasty, heart failure, heart transplant, other cardiac diagnoses, or unknown.
Hospital length of stay	This is a categorical variable where the period between the date of hospital admission and the date of hospital discharge was calculated, and then it was classified according to percentiles based where the percentile 25 = 6 days, percentile 50 (median) = 9 and percentile 75 = 17: ▪ ≤ 6 days (i.e., from 1 to 25th percentile). ▪ 7-9 days (i.e., more than 25th percentile to 50th percentile). ▪ 10-17 days (i.e., more than 50th percentile to 75th percentile). ▪ ≥ 18 days (i.e., more than 75th percentile).
Confirmed joining date	The variable is a binary recoding (No, Yes) for if the patient had a confirmed date to join CR.

CR: cardiac rehabilitation. CABG: coronary artery bypass grafting. WT: waiting time. ACS: acute coronary syndrome. MI: myocardial infarction. AMI: acute myocardial infarction. PCI: percutaneous coronary intervention.

Table 3.2 The Study Categorisations for Partnership Status, Ethnicity and Number of Comorbidities

Variable names	NACR source data	Thesis categorisations	
Partnership Status	Married	Partnered	
	Permanent Partnership		
	Single	Not partnered	
	Divorced		
	Widowed		
	Separated		
Ethnicity	White – British	White	
	White – Irish		
	White – Any other White background		
	Mixed/Multiple ethnic groups – White and Black Caribbean		
	Mixed/Multiple ethnic groups – White and Black African		
	White and Asian		
	Asian/Asian British – Indian	Asian	Non-white
	Asian/Asian British – Pakistani		
	Asian/Asian British – Bangladeshi		
	Asian/Asian British – Any other Asian background		
	Asian/Asian British – Chinese		
	Black/African/Caribbean/Black British – Caribbean	Black	
	Black/African/Caribbean/Black British – African		
	Black/African/Caribbean/Black British – Any other Black background		
	Mixed/Multiple ethnic groups – Any other mixed background	Other	
	Other ethnic groups – Any other ethnic group		
	Not Stated		
Number of comorbidities	No comorbidity	No comorbidity	
	1 comorbidity	1-2 comorbidities	
	2 comorbidities		
	3 comorbidities	≥ 3 comorbidities	
	4 comorbidities		
	5 comorbidities		
	6 comorbidities		
	7 comorbidities		
	8 comorbidities		
	9 comorbidities		
	10 comorbidities		
	11 comorbidities		
	12 comorbidities		
	13 comorbidities		

NACR: National Audit of Cardiac Rehabilitation.

3.4 Data Analysis

The initial analysis used descriptive statistics of mean and standard deviation (SD) for continuous variables and percentages and counts for the categorical variables, as well as minimum and maximum, to inform the validity of the waiting time periods. Additionally, where appropriate, inferential statistics were used as independent samples t-tests to compare the means of 2 continuous variables, and the tests would be statistically significant if the p-value < 0.05. While chi-square tests were used for categorical variables, the alpha value was adjusted because the multiple comparisons using Bonferroni correction were 0.003, i.e., the test was statistically significant if the p-value < 0.003. 'As recommended by other analyses, age was centred to mean age to make the intercept value in the regression equation equal to a dependent variable when age is centred (Newton and Rudestam, 2017). Since the starting CR variable is binary, logistic regression with a backwards selection method was used with identified factors tested as independent variables to examine its association with the outcomes of starting CR. In addition to the primary logistic regression analysis that included waiting time as a binary variable (≤ 6 weeks WT, > 6 weeks WT), 2 regression analyses were conducted, each with the other forms of waiting time, i.e., the multicategory variables with an increase 2-week interval and a continuous variable (WT in weeks). The model was built in 5 blocks: block one (treatment type, waiting time), block 2 (age, gender, interaction age*gender), block 3 (ethnicity, previous CR, SES), block 4 (partnership status), block 5 (all cardiac-event factors except treatment type). Each model was evaluated, and its assumption was assessed, as mentioned in the methodology, chapter 2, section 2.4.1.

3.5 Results

3.5.1 Descriptive and Inferential Statistics

There were 123,942 adult patients (18 years and older) who had CABG, valve surgeries or both between January 2013 and October 2019, according to the NACR database. The number of cases with a valid waiting time included in the study was 93,869 patients, while 32,849 cases were included in the logistic regression (see Figure 3.1).
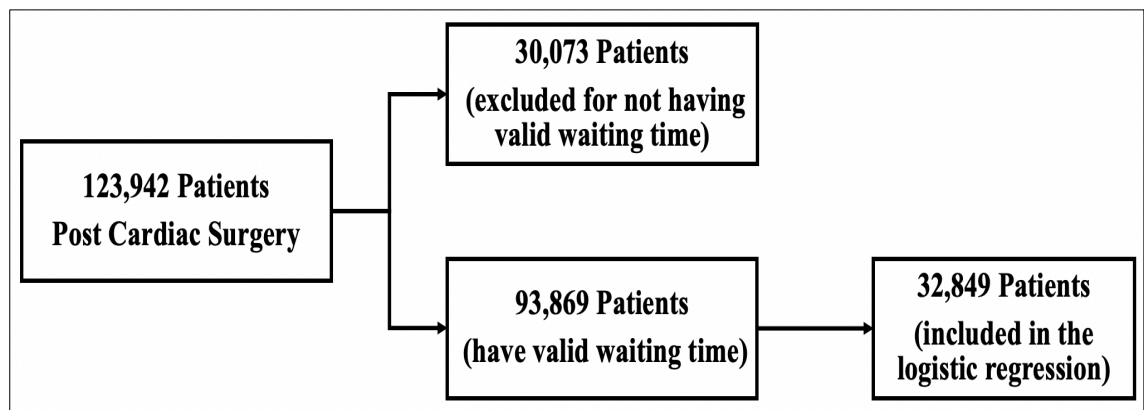
Figure 3.1 Flow Chart of the Study Sample

Table 3.3 shows the distribution and representation of males and females with mean ages for the 3 treatment types. The largest group was post-CABG (51,606 patients), with men the majority (83.2%), while women were older, with a mean of 68 years. The treatment type of valve surgeries (30,328 patients) shows women with a mean age similar to the previous group, making up 39.6% of the patients. The last treatment type was patients who underwent both CABG and valve surgeries (11.1%), with men being the majority and, on average younger. Figure 3.2 illustrates the percentage of men and women who had one of the 3 treatment types.

The following section describes the statistical findings related to the outcome of starting CR (No, Yes). The potential factors related to starting CR were classified according to the data field collected by the NACR, i.e., patient and cardiac-event factors (in addition to waiting time).

Table 3.3 Age and Gender by Treatment Type

Treatment Type	CABG		Valve Surgeries		CABG/valve		Total	
Gender	Age Mean (SD) years	Count (%)	Age Mean (SD) years	Count (%)	Age Mean (SD) years	Count (%)	Age Mean (SD) years	Count (%)
Male	66.0 (10)	42,954 (83.2)	65.0 (13)	18,327 (60.4)	72.0 (9)	7,722 (75.6)	66.0 (11)	69,003 (74.9)
Female	68.0 (10)	8,652 (16.8)	68.0 (13)	12,001 (39.6)	74.0 (8)	2,490 (24.4)	69.0 (12)	23,143 (25.1)
Total	66.0 (10)	51,606 (56.0)	66.0 (13)	30,328 (32.9)	72.0 (9)	10,212 (11.1)	67.0 (11)	92,146* (100)

%: percentage. CABG: coronary artery bypass grafting. SD: standard deviation.
*Some patients did not have their gender data completed and thus were removed.
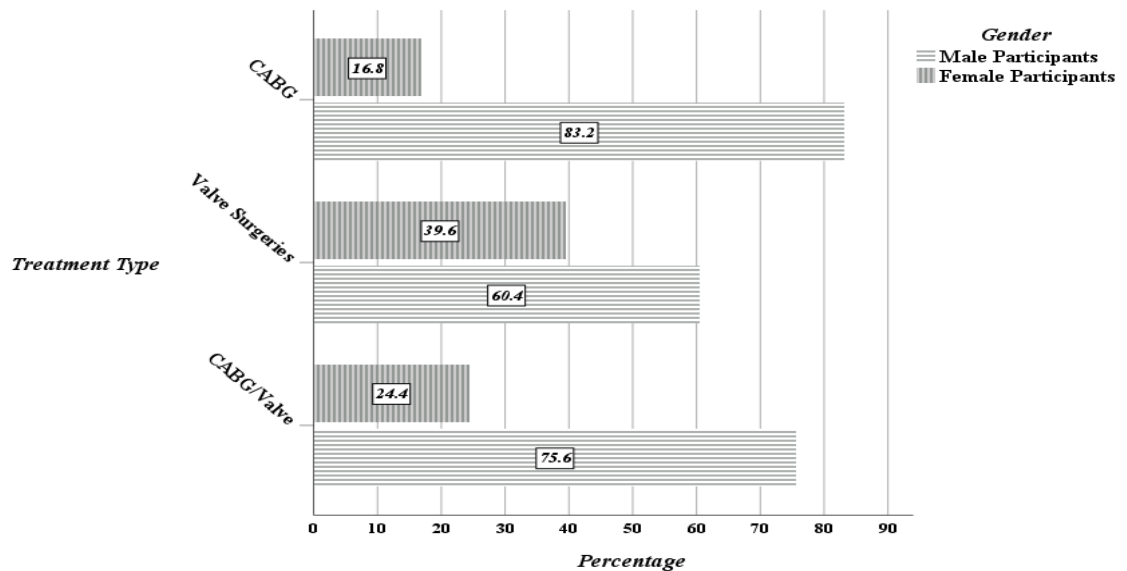
Figure 3.2 Gender by Treatment Type
CABG: coronary artery bypass grafting.

3.5.1.1 Waiting Time

Testing the association between the 2 categories of waiting time of ≤ 6 weeks WT and > 6 weeks in relation to starting CR for the 93,869 patients with valid waiting time was found to be significant $\chi^2 (1) = 3,791.6$. There were 68,580 (73.1%) patients who had started CR, compared to 25,289 (26.9%) patients who did not. For the group that started

CR, the number of patients in both waiting times was approximately equal, with 47.0%

in ≤ 6 weeks WT and 53.0% in > 6 weeks WT (see Table 3.4).

Table 3.4 Cross-Tabulations for Waiting Time and Starting CR Variable

Waiting time Factor		Starting CR (NO)	Starting CR (YES)	Chi-square	df	p-value*
		Count (%)	Count (%)			
Waiting time N = 93,869 patients	**≤ 6 weeks WT**	17,597 (69.6)	32,216 (47.0)	3,791.6	1	< 0.001
	> 6 weeks WT	7,692 (30.4)	36,364 (53.0)			
	Total	25,289 (100)	68,580 (100)			

* Significant if p-value < 0.05.
%: percentage. CR: cardiac rehabilitation. WT: waiting time. SD: standard deviations. df: degrees of freedom.

3.5.1.2 Patient Factors

Table 3.5 shows 6 patient factors associated with starting CR: age, gender, ethnicity, partnership status, SES, and previous CR. The mean age of the patients was 67.8 (SD = 12) years in the population who did not start CR compared to the patients that started CR, where the mean age was 66.6 (SD = 11) years. The Independent t-test showed significant statistical differences t (9,3867) = 14.8, although the mean difference was only 1.2 years. In addition, there was a significant association between gender and the 2 possible outcomes of starting CR (yes or no) χ^2 (1) = 200.8, with males representing the majority in each group of not starting or starting CR. The ethnicity of white and non-white (Asian, Black, and other) was represented almost equally in both outcomes of starting CR by 87.1% and 12.9% in no starting CR and 87.0% and 13.0% in starting CR, respectively. Both categories of ethnicities showed a nonsignificant association with starting CR variable χ^2 (1) = 0.1. There was an association between whether being partnered or not partnered with the starting CR χ^2 (1) = 98.8, with being partnered making the majority with 75.4% in not starting CR and 77.7% in starting CR. The SES ranking was associated with starting/not starting CR. Among patients who started CR, patients with first quintile status (most deprived) were the minority making 7,436 (13.4%), and as the SES rank

increased, the number of patients starting CR also increased to 14,721 (26.6%). The starting CR variable was found to be significantly associated with the patients' history of CR, as the percentage of patients with previous CR and who did not start CR was higher than those who started CR by 4.9% to 1.8%, respectively. The majority of patients in either category of the starting CR variable had no previous history of participating in the CR programme.

Table 3.5 Cross-Tabulations for Patient Factors and Starting CR Variable

Patient Factors		Starting CR (NO)		Starting CR (YES)		t-value	df	p-value*
		Count (%)	Mean (SD)	Count (%)	Mean (SD)			
Age (In years)		25,289 (26.9)	67.8 (12)	68,580 (73.1)	66.6 (11)	14.8	93,867	< 0.001
Patient Factors		Count (%)		Count (%)		Chi-square	df	p-value**
Gender	Male	17,806 (71.6)		51,197 (76.1)		200.8	1	< 0.001
	Female	7,078 (28.4)		16,065 (23.9)				
Ethnicity	White	17,491 (87.1)		50,558 (87.0)		0.1	1	0.751
	Non-white	2,597 (12.9)		7,565 (13.0)				
Partnership status	Partnered	11,861 (75.4)		37,808 (79.2)		98.8	1	< 0.001
	Not partnered	3,868 (24.6)		9,942 (20.8)				
SES	First quintile	3,606 (17.2)		7,436 (13.4)		343.0	4	< 0.001
	Second quintile	3,948 (18.8)		9,244 (16.7)				
	Third quintile	4,283 (20.4)		11,190 (20.2)				
	Fourth quintile	4,604 (21.9)		12,846 (23.2)				
	Fifth quintile	4,553 (21.7)		14,721 (26.6)				
Previous CR	Previous CR	1,228 (4.9)		1,221 (1.8)		687.8	1	< 0.001
	No previous CR	24,061 (95.1)		67,359 (98.2)				

* Significant if p-value < 0.05. ** Significant after Bonferroni correction for multiple testing if p-value < 0.003.

%: percentage. CR: cardiac rehabilitation. SD: standard deviations. df: degrees of freedom. SES: socioeconomic status.

3.5.1.3 Cardiac-Event Factors

Fourteen cardiac-event factors associated with starting CR were identified (see Table 3.6). There was an association between different treatment types (CABG, valve Surgeries, CABG/valve) and starting CR. Among both categories of not starting CR or starting CR, patients who had undergone CABG form 52.7% (and 57.3%), then heart valve surgeries form 35.4% (and 31.9%), with patients who underwent both surgeries making up 11.9% (10.8%). There was an association between the 2 outcomes of starting CR and patients responding yes or no to any of the 7 comorbidities of angina, anxiety, depression, diabetes mellitus, hypertension, hyperlipidaemia, and family history of CVD. Within the group that started CR, patients with none of those comorbidities mentioned earlier make up the majority by two-thirds or more, except for hypertension, where patients diagnosed with this condition make up 53.7% compared to 46.3% of patients who did not have it. There was an association between the 2 starting CR categories and having no comorbidity, 1-2 comorbidities, or ≥ 3 comorbidities $\chi^2 (2) = 34.16$. In both starting CR categories, patients tended to have 1-2 or 3 comorbidities compared to not having comorbidities. Having a previous history of CABG surgery was not common in this patient population, combined with the initial analysis that found a nonsignificant association with starting CR, meant the low number of cases with this variable (prior CABG) was not included in the regression. There was a nonsignificant association between starting CR and being diagnosed with≥ 2 cardiac events of CABG, valve surgeries, PCI, and AMI. At the same time, there was a significant association with having/not having a history of one of these previous cardiac events (MI, cardiac arrest, pacemaker implantation, left ventricular assist device, acute coronary syndrome (ACS), angina, implantable cardioverter-defibrillator, CABG, other surgery, congenital heart defect, coronary angioplasty, heart failure, heart transplant, other cardiac diagnoses, unknown).

Table 3.6 Cross-Tabulations for Cardiac-Event Factors and Starting CR Variable

Cardiac-Event Factors		Starting CR (NO) Count (%)	Starting CR (YES) Count (%)	Chi-square	df	p-value*
Treatment type	CABG	13,333 (52.7.0)	39,275 (57.3)	155.2	2	< 0.001
	valve Surgeries	8,956 (35.4.0)	21,900 (31.9)			
	CABG/valve	3,000 (11.9.0)	7,405 (10.8)			
Angina	No	12,371 (81.1)	41,266 (81.9)	5.2	1	0.023
	Yes	2,888 (18.9)	9,128 (18.1)			
Diabetes mellitus	No	11,099 (72.7)	38,239 (75.9)	61.9	1	< 0.001
	Yes	4,160 (27.3)	12,155 (24.1)			
Hypertension	No	6,712 (44.0)	23,344 (46.3)	25.7	1	< 0.001
	Yes	8,547 (56.0)	27,050 (53.7)			
Anxiety	No	14,656 (96.0)	47,860 (95.0)	29.8	1	< 0.001
	Yes	603 (4.0)	2,534 (5.0)			
Depression	No	14,520 (95.2)	47,534 (94.3)	15.7	1	< 0.001
	Yes	739 (4.8)	2,860 (5.7)			
Family history of CVD	No	12,028 (78.8)	37,287 (74.0)	146.5	1	< 0.001
	Yes	3,231 (21.2)	13,107 (26.0)			
Hyperlipidaemia	No	10,266 (67.3)	32,176 (63.8)	60.3	1	< 0.001
	Yes	4,993 (32.7)	18,218 (36.2)			
Number of comorbidities	No comorbidity	474 (3.1)	1,921 (3.8)	34.2	2	< 0.001
	1-2 comorbidities	7,895 (51.7)	24,932 (49.5)			
	≥ 3 comorbidities	6,890 (45.2)	23,541 (46.7)			
Previous CABG	No	9,108 (94.7)	31,065 (94.2)	3.1	1	0.080
	Yes	510 (5.3)	1,903 (5.8)			
A diagnosis of ≥ 2 cardiac events	CABG or/and valve surgeries	21,441 (84.8)	58,170 (84.8)	3.5	3	0.319
	CABG or/and valve surgeries + AMI	3,538 (14.0)	9,505 (13.9)			
	CABG or/and valve surgeries + PCI	109 (0.4)	278 (0.4)			
	CABG or/and valve surgeries + AMI/PCI	201 (0.8)	627 (0.9)			
Previous cardiac events	No previous events	17,526 (69.3)	44,870 (65.4)	124.5	1	< 0.001
	Previous events	7,763 (30.7)	23,710 (34.6)			
Hospital length of stay	≤ 6 days	5,946 (28.3)	17,374 (30.1)	64.2	3	< 0.001
	7-9 days	5,033 (24.0)	14,658 (25.4)			
	10-17 days	5,032 (24.0)	12,723 (22.0)			
	≥18 days	4,999 (23.8)	13,039 (22.6)			
Confirmed joining date	No	13,062 (51.7)	17,833 (26.0)	5,504.3	1	< 0.001
	Yes	12,227 (48.3)	50,747 (74.0)			

* Significant after Bonferroni correction for multiple testing if p-value < 0.003

%: percentage, AMI: Acute myocardial infarction. CABG: coronary artery bypass grafting. CR: cardiac rehabilitation. CVD: cardiovascular disease. PCI: percutaneous coronary intervention. SD: standard deviations. df: degrees of freedom.

There was a significant association between the starting CR and patients with different hospital length of stay periods $\chi^2 (3) = 64.2$. Within the 4 categories of a hospital length of stay, 30.1% would stay at the hospital for the minimum period, then 24.4% of patients would stay 7-9 days, with the rest two lengths of stay having an approximately equal number of patients of 22.0% and 22.6% for 10-17 days and ≥18 days respectively. There was an association between the starting CR and having/not having a confirmed joining date and referral. The percentage of patients who started CR who had confirmed the joining date was higher (74.0%) than those who had no joining date confirmation (26.0%).

3.5.2 Waiting Time to Start CR

Based upon the aim of this chapter, this section focused on the association between waiting time and starting CR. Inspecting the distribution of patients for the 3 measurements of waiting time is shown in (see Table 3.7). There were 93,869 patients with recorded waiting times to start CR ranging from 0 to 52 weeks. There was a slight difference in the percentage of patients who waited up to 6 weeks to start CR compared to those who waited for more by 53.1% and 46.9%, respectively.

Table 3.7 Patients Distribution in the 3 Measurements of Waiting Time

Waiting Time 3 Measurements		Count (%)
Waiting time (Continuous variable)	0 – 52 weeks	93,869 (100)
Waiting time (Binary variable)	≤ 6 weeks WT	49,813 (53.1)
	> 6 weeks WT	44,056 (46.9)
Waiting time (Multicategories variable)	WT ≤ 2 weeks	21,839 (23.3)
	2 > WT ≤ 4 weeks	14,431 (15.4)
	4 > WT ≤ 6 weeks	13,543 (14.4)
	6 > WT ≤ 8 weeks	18,072 (19.3)
	WT > 8 weeks	25,984 (27.7)

WT: waiting time, %: percentage.

Table 3.8 Starting CR in the 3 Treatment Types

Treatment Types		≤ 6 weeks WT Count (%)	> 6 weeks WT Count (%)	Chi-square	df	p-value*
CABG	No	9,135 (32.6)	4,198 (17.0)	1,685.7	1	< 0.001
	Yes	18,844 (67.4)	20,431 (83.0)			
Valve Surgeries	No	6,368 (38.5)	2,588 (18.1)	1,564.4	1	< 0.001
	Yes	10,153 (61.5)	11,747 (81.9)			
CABG/valve	No	2,094 (39.4)	906 (17.8)	592.3	1	< 0.001
	Yes	3,219 (60.6)	4,186 (82.2)			
Total	No	17,597 (35.3)	7,692 (17.5)	3,791.6	1	< 0.001
	Yes	32,216 (64.7)	36,364 (82.5)			

* Significant if p-value < 0.05.
%: percentage. WT: waiting time. CABG: coronary artery bypass grafting. df: degrees of freedom.

Further analysis using waiting time expressed in 5 categories (split by 2-week intervals) shows a higher percentage of patients (27.7%) who waited more than 8 weeks, followed by 23.3% for waiting time ≤ 2 weeks. Among the population of each of the 3 treatment types, there was a significant association between starting CR variable and the 2 waiting times (≤ 6 weeks WT and > 6 weeks WT) (see Table 3.8). From here on, according to the literature and the research question, waiting time would be used as a binary variable, i.e., up to 6 weeks and more than 6 weeks.

Tables 3.9 and 3.10 are cross-tabulations examining the relationship between patient and cardiac-event factors with waiting time. The mean age of the patients was 67.2 (SD = 11) years in the longer waiting time, which was older compared to the patients in the shorter waiting time, where the mean age was 66.7 (SD = 11) years. Men represented the majority

in each waiting time period making up three quarters compared to women. The ethnicity of white and non-white was represented almost equally in both time periods by 87.6% and 12.4% in ≤ 6 weeks and 86.4% and 13.6% in > 6 weeks, respectively. Being partnered made the majority, with 78.8% in the short time period and 77.7% in the extended time period. Patients within the first to third quintiles would wait less to start CR than patients from the fourth to fifth quintiles, with an unnoticeable difference between the 2 waiting times. The majority of patients had no history of participating in the CR programme.

Table 3.9 Cross-Tabulations for Patient Factors and Waiting Time

Patient Factors			≤ 6 weeks WT		> 6 weeks WT	
			Continuous Variable			
			Count (%)	Mean (SD)	Count (%)	Mean (SD)
Age (In years)			49,813 (53.1)	66.7 (11)	44,056 (46.9)	67.2 (11)
Patient Factors			**Categorical Variables**			
			Count (%)		**Count (%)**	
Gender	Male		36,743 (75.2)		32,260 (74.5)	
	Female		12,096 (24.8)		11,047 (25.5)	
	Total		48,839 (100)		43,307 (100)	
Ethnicity	White		35,996 (87.6)		32,048 (86.4)	
	Non-white		5,097 (12.4)		5,062 (13.6)	
Partnership status	Partnered		25,420 (78.8)		24,249 (77.7)	
	Not partnered		6,859 (21.2)		6,951 (22.3)	
SES	First quintile		6,297 (15.5)		4,745 (13.3)	
	Second quintile		7,302 (18.0)		5,890 (16.5)	
	Third quintile		8,386 (20.6)		7,087 (19.8)	
	Fourth quintile		8,993 (22.1)		8,457 (23.7)	
	Fifth quintile		9,701 (23.8)		9,573 (26.8)	
Previous CR	Previous CR		1,523 (3.1)		926 (2.1)	
	No previous CR		48,290 (96.9)		43,130 (97.9)	

%: percentage. WT: waiting time. SD: standard deviations. CR: cardiac rehabilitation. SES: socioeconomic status.

Table 3.10 Cross-Tabulations for Cardiac-Event Factors and Waiting Time

Cardiac-Event Factors		≤ 6 weeks WT	> 6 weeks WT
		Count (%)	Count (%)
Treatment type	**CABG**	27,979 (56.2)	24,629 (55.9)
	Valve Surgeries	16,521 (33.2)	14,335 (32.5)
	CABG/valve	5,313 (10.7)	5,092 (11.6)
Angina	**No**	26,239 (81.0)	27,398 (82.4)
	Yes	6,148 (19.0)	5,868 (17.6)
Diabetes mellitus	**No**	24,427 (75.4)	24,911 (74.9)
	Yes	7,960 (24.6)	8,355 (25.1)
Hypertension	**No**	14,926 (46.1)	15,130 (45.5)
	Yes	17,461 (53.9)	18,136 (54.5)
Anxiety	**No**	31,010 (95.7)	31,506 (94.7)
	Yes	1,377 (4.3)	1,760 (5.3)
Depression	**No**	30,746 (94.9)	31,308 (94.1)
	Yes	1,641 (5.1)	1,958 (5.9)
Family history of CVD	**No**	24,568 (75.9)	24,747 (74.4)
	Yes	7,819 (24.1)	8,519 (25.6)
Hyperlipidaemia	**No**	21,094 (65.1)	21,348 (64.2)
	Yes	11,293 (34.9)	11,918 (35.8)
Previous CABG	**No**	19,633 (94.1)	20,540 (94.6)
	Yes	1,238 (5.9)	1,175 (5.4)
A diagnosis of ≥ 2 cardiac events	**CABG and/or valve**	42,560 (85.4)	37,051 (84.1)
	CABG and/or valve plus AMI	6,702 (13.5)	6,341 (14.4)
	CABG and/or valve plus PCI	190 (0.4)	197 (0.4)
	CABG and/or valve plus AMI + PCI	361 (0.7)	467 (1.1)
Number of comorbidities	**No comorbidity**	1,234 (3.8)	1,161 (3.5)
	1-2 comorbidities	16,480 (50.9)	16,347 (49.1)
	≥ 3 comorbidities	14,673 (45.3)	15,758 (47.4)
Previous cardiac events	**No previous events**	34,074 (68.4)	28,322 (64.3)
	Previous events	15,739 (31.6)	15,734 (35.7)
Hospital length of stay	**≤ 6 days**	13,287 (31.7)	10,033 (27.2)
	7-9 days	11,152 (26.6)	8,539 (23.2)
	10-17 days	9,638 (23.0)	8,117 (22.0)
	≥18 days	7,891 (18.8)	10,147 (27.5)
Confirmed joining date	**No**	19,025 (38.2)	11,870 (26.9)
	yes	30,788 (61.8)	32,186 (73.1)

%: percentage. AMI: acute myocardial infarction. CABG: coronary artery bypass grafting. CR: cardiac rehabilitation. CVD: cardiovascular disease. PCI: percutaneous coronary intervention.

Patients who had undergone CABG represented 56.2% of the sample, the heart valve surgeries formed 33.2%, and patients who underwent both surgeries made up the remaining 11.0% in the short and long waiting times. The most common comorbidities in the 2 waiting times groups were hypertension, hyperlipidaemia, diabetes mellitus and family history. Having a history of previous CABG was not common in the sample. Patients who were diagnosed with more than two cardiac events formed low percentages. In both different waiting times, there were more patients with 1-2 or $\geq$ 3 comorbidities than patients with no comorbidity. In the $\leq$ 6 weeks WT group, most patients had a hospital length of stay of $\leq$ 6 days (31.7%) or 7-9 days (26.6%), while for > 6 weeks WT group (27.2%) for $\leq$ 6 days and (27.5%) for $\geq$18 days. In addition, more patients had a confirmed joining date for both waiting times compared to those who did not.

3.5.3 Factors Associated With Starting CR

Twenty-one factors were coded as independent variables in a binary logistic regression related to starting/ not starting CR as a dependent variable using backward elimination and 32,849 cases (with completed data). The final model was statistically significant, χ^2 (22) = 4,252.5, with the model explaining 18.5% (Nagelkerke R^2) of the variance in starting CR and correctly classifying 79.7% of cases (see Table 3.11).

Hosmer and Lemeshow test value χ^2 (8) = 69.681 and p-value < 0.05 (i.e., statistically significant), which could be due to this study's large sample size where the test considers minor differences significant (Kramer and Zimmerman, 2007).

The measures of classification performance were computed at the default cut-off point of 0.50, which resulted in a high sensitivity but low specificity, and since the relationship between both values represents a trade-off, a new cut-off point (0.790) was chosen to maximise both values (see Table 3.12). The ROC curve test indicates that the model has a good predictive ability with an AUC of 0.730 (SE (standard error) = 0.003, 95% CI: 0.723, 0.736) (see Figure 3.3).

Table 3.11 The Binary Logistic Regression 5 Blocks

The Regression Blocks	Factors	−2 Log likelihood	Nagelkerke R^2	Overall Model accuracy
Block 1	1. **Treatment type**	33,561.361	0.066	77.5%
	2. **Waiting time**			
Block 2	3. **Age (mean-centred)**	33,369.761	0.074	77.5%
	4. **Gender**			
	5. **Interaction age*gender**			
Block 3	6. **Ethnicity**	32,986.906	0.091	77.8%
	7. **Previous CR**			
	8. **SES**			
Block 4	9. **Partnership status**	32,969.033	0.092	77.8%
Block 5	10. **Angina**	30,757.906	0.185	79.7%
	11. **Diabetes mellitus**			
	12. **Hypertension**			
	13. **Anxiety**			
	14. **Depression**			
	15. **Family history of CVD**			
	16. **Hyperlipidaemia**			
	17. **Number of comorbidities**			
	18. **A diagnosis of ≥ 2 cardiac events**			
	19. **Hospital length of stay**			
	20. **Confirmed joining date**			
	21. **Previous cardiac events**			

%: percentage. AMI: acute myocardial infarction. CABG: coronary artery bypass grafting. CR: cardiac rehabilitation. CVD: cardiovascular disease. PCI: percutaneous coronary intervention. SES: socioeconomic status

Table 3.12 The Measures of Classification Performance at Different Cut-Off Points

classification performance	cut-off point (0.500)	a new cut-off point (0.790)
Sensitivity	95.7%	65.6%
Specificity	24.5%	67.5%

ROC Curve

Diagonal segments are produced by ties.
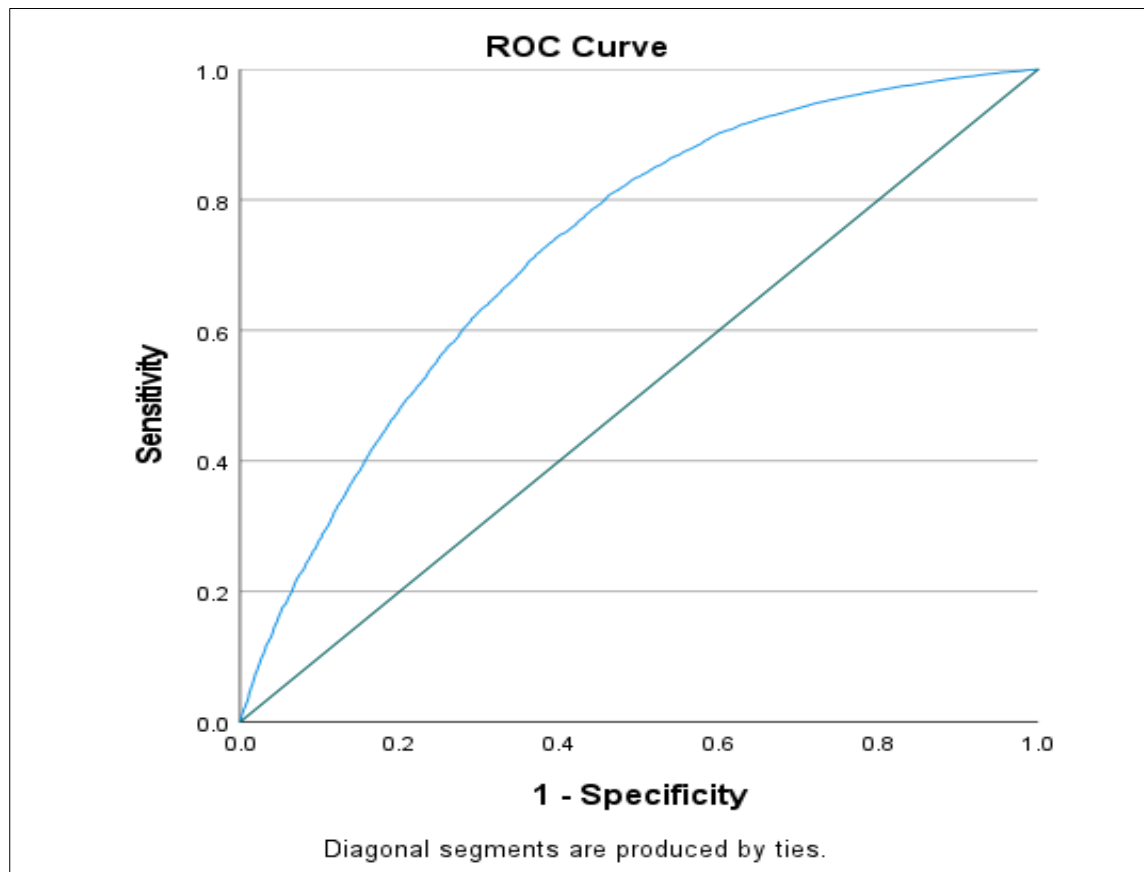
Figure 3.3 ROC Curve for Final Starting CR Model

3.5.3.1 Model Assumptions

The assumptions of the dependent variable being binary and the observations being independent of each other were met since the regression dependent was coded (0,1) for not starting or starting CR, and the observed data were not dependent, like being results of repeated measures (see Table 3.1). Regarding the sample size, the analysis had 32,849, which exceeded the recommended minimum sample size. Furthermore, the collinearity diagnostic statistics were checked, where its outcomes tolerance was close to 1 then 0 and

VIF all less than 10, which means there was no multicollinearity between the independent variables.

Another assumption tested was linearity in the logit that involves the continuous variables in the analysis. The first continuous variable was age (mean centring), which has values less than zero; therefore, log transformation is not possible, making the variable invalid for the assumption test. The second continuous variable was age interaction with gender, where the interaction between the variable and its log transformation was found to be nonsignificant (p-value = 0.114), which means the assumption was met.

The final assumption checked was that the data was without highly influential values by examining the standardised residuals, cook's distance and DFBeta, and they were all within the recommended limit. There was also the leverage, and they were investigated to find if they were larger than 3 (k + 1) / n = 3 (22) / 32,855 = 0.002. After examining the leverage value, it became apparent that specific ethnicity categories distort the analysis. A slight change in how these categories were defined. i.e., changed ethnicity classification from a multicategory variable to a binary variable (white, non-white) to improve the distribution. This approach has been used in several published research (Grace et al., 2011; Prince et al., 2014; Johnson et al., 2014; Zhang et al., 2017). The leverage value against the cook's distance was plotted again, where there was a noticeable improvement compared to the first plot; however, there were 6 cases that had the highest leverage, which was examined and removed (Appendix F).

3.5.3.2 Significant Factors Associated With Starting CR

The regression analysis of the 21 independent factors resulted in 15 significant factors associated with starting CR (see Table 3.13 and Figure 3.4). For a more detailed table of the regression outcomes, see Appendix G; for unadjusted OR from the logistic regression, see Appendix H.

Table 3.13 Logistic Regression Results for Starting Cardiac Rehabilitation

Factors (reference)		OR	1/ OR	95% CI		p-value*
				Lower	Upper	
Waiting time (≤ 6 weeks WT)	> 6 weeks WT	2.55	-	2.41	2.70	< 0.001
Age (Mean centring)	In years	0.99	-	0.98	0.99	< 0.001
Gender (Male)	Female	0.85	1.18	0.79 (1.10)	0.91 (1.26)	< 0.001
Gender* Age	-	0.99	-	0.98	0.99	< 0.001
Ethnicity (White)	Non-white	1.11	-	1.01	1.21	< 0.001
Partnership status (Not partnered)	Partnered	1.13	-	1.06	1.21	< 0.001
SES (First quintile most deprived)	Second quintile	1.18	-	1.07	1.30	< 0.001
	Third quintile	1.36	-	1.23	1.50	< 0.001
	Fourth quintile	1.32	-	1.20	1.45	< 0.001
	Fifth quintile	1.67	-	1.52	1.83	< 0.001
Previous CR (Previous CR)	No previous CR	2.76	-	2.35	3.24	< 0.001
Treatment type (CABG)	Valve surgeries	0.88	1.14	0.82 (1.07)	0.94 (1.22)	< 0.001
	CABG/valve	0.89	1.13	0.81	0.97	< 0.001
Diabetes mellitus (No)	Yes	0.86	1.16	0.81 (1.09)	0.92 (1.24)	<0.001
Family history of CVD (No)	Yes	1.29	-	1.21	1.38	<0.001
Hyperlipidaemia (No)	Yes	1.11	-	1.04	1.18	<0.001
Previous cardiac events (No)	Yes	0.74	1.35	0.70 (1.27)	0.79 (1.43)	<0.001
Hospital length of stay (≤ 6 days)	7-9 days	1.07	-	0.99	1.15	0.090
	10-17 days	0.92	1.09	0.85 (1.01)	0.99 (1.17)	< 0.001
	≥18 days	0.90	1.11	0.83 (1.03)	0.97 (1.21)	< 0.001
Confirmed joining date (No)	Yes	3.80	-	3.58	4.02	< 0.001

* Significant if p-value < 0.05.

Note: Not significant Variables (angina, hypertension, anxiety, depression, number of comorbidities, previous CABG, a diagnosis of ≥ 2 cardiac events).

%: percentage. AMI: acute myocardial infarction. CABG: coronary artery bypass grafting. CR: cardiac rehabilitation. CVD: cardiovascular disease. PCI: percutaneous coronary intervention. WT: waiting time. OR: odds ratio. CI: confident intervals. SES: socioeconomic status.

Significant Independent Factors		Odds Ratio [95% CL]
Previous events (Yes)		0.74 [0.70, 0.79]
Gender (Female)		0.85 [0.79, 0.91]
Diabetes (Yes)		0.85 [0.79, 0.91]
Treatment type (Valve Surgeries)		0.88 [0.82, 0.94]
Treatment type (CABGPlusValve)		0.89 [0.81, 0.97]
Hospital length of stay (> 18 days)		0.90 [0.83, 0.97]
Hospital length of stay (10-17 days)		0.92 [0.85, 0.99]
Hospital length of stay (7-9 days)		1.07 [0.99, 1.15]
Ethnicity (Non-white)		1.11 [1.01, 1.21]
Hyperlipidaemia (Yes)		1.11 [1.04, 1.18]
Partnership status (Partnered)		1.13 [1.06, 1.21]
SES (2nd Quintile)		1.18 [1.07, 1.30]
Family history of CVD (Yes)		1.29 [1.21, 1.38]
SES (4th Quintile)		1.32 [1.20, 1.45]
SES (3rd Quintile)		1.36 [1.23, 1.50]
SES (5th Quintile)		1.67 [1.52, 1.83]
Waiting time (> 6 weeks)		2.55 [2.41, 2.70]
Previous CR (No)		2.76 [2.35, 3.24]
Confirmed joining date (Yes)		3.80 [3.58, 4.02]

-0.80   -0.50   -0.20   0.10   0.40   0.70   1.00   1.30   1.60   1.90   2.20   2.50   2.80   3.10   3.40   3.70   4.00   4.30   4.60

Not Starting CR   Starting CR

Figure 3.4 Forest Plot of Significant Independent Factors From Regression Analysis for Starting CR.

CABG: coronary artery bypass grafting. SES: socioeconomic status. CVD: cardiovascular disease.

3.5.3.2.1 Waiting Time

The factor of waiting time from the treatment date to starting CR was put into 3 different models to investigate how the 3 measurements of waiting time were associated with CR starting CR (see Table 3.14). In the first model, waiting time was categorical; the patient who waited > 6 weeks to start CR had 2.55 times the odds of starting CR (95% CI: 2.41, 2.70) compared to those waiting less than 6 weeks. The second model, the waiting time as a multicategory variable, showed that the high waiting time of $6 > WT \leq 8$ weeks was associated with a high OR: 6.83 (95% CI: 6.21, 7.50). Finally, the third model (WT in weeks) showed that with every increase in waiting time by 1 week, there was an increase of 13.0% in the probability of starting CR.

Table 3.14 The 3 Measures of Waiting Time From 3 Different Models of Logistic Regression

Factors (reference)		OR	95% CI		p-value*
			Lower	Upper	
Waiting time (≤ 6 weeks WT)	> 6 weeks WT	2.55	2.41	2.70	< 0.001
Waiting time (WT ≤ 2 weeks)	$2 > WT \leq 4$ weeks	2.79	2.55	3.05	< 0.001
	$4 > WT \leq 6$ weeks	5.39	4.91	5.91	< 0.001
	$6 > WT \leq 8$ weeks	6.83	6.21	7.50	< 0.001
	WT > 8 weeks	6.34	5.85	6.88	< 0.001
Waiting time	In weeks	1.13	1.13	1.14	< 0.001

*Significant if p-value < 0.05.
WT: waiting time. OR: odds ratio. CI: confident intervals.

3.5.3.2.2 Patient Factors

The odds of starting CR decrease by 1% (OR: 0.99, 95% CI: 0.98, 0.99) for every increase in age by a year. Male patients were more likely by 1.18 times to start CR compared to female patients (95% CI: 1.10, 1.26). There was an interaction between age and gender with OR = 0.99 (see Figure 3.5). Patients identified as non-white ethnicity had a chance

of 11.0% (OR: 1.11, 95% CI: 1.01, 1.21) starting CR compared to those who identified as white. Compared to not partnered, partnered patients had the odds of 1.13 times (95% CI: 1.06, 1.21) of starting CR. As for SES, patients who fall at the fifth quintile (least-deprived) at the Index of Multiple Deprivation (IMD) scores were 67.0% more likely to start CR compared to the first quintile (most-deprived) (OR: 1.67, 95% CI: 1.52, 1.83). Having no history of previous CR would increase the odds of starting CR by 2.76 times (95% CI: 2.35, 3.24) compared to having a previous CR.
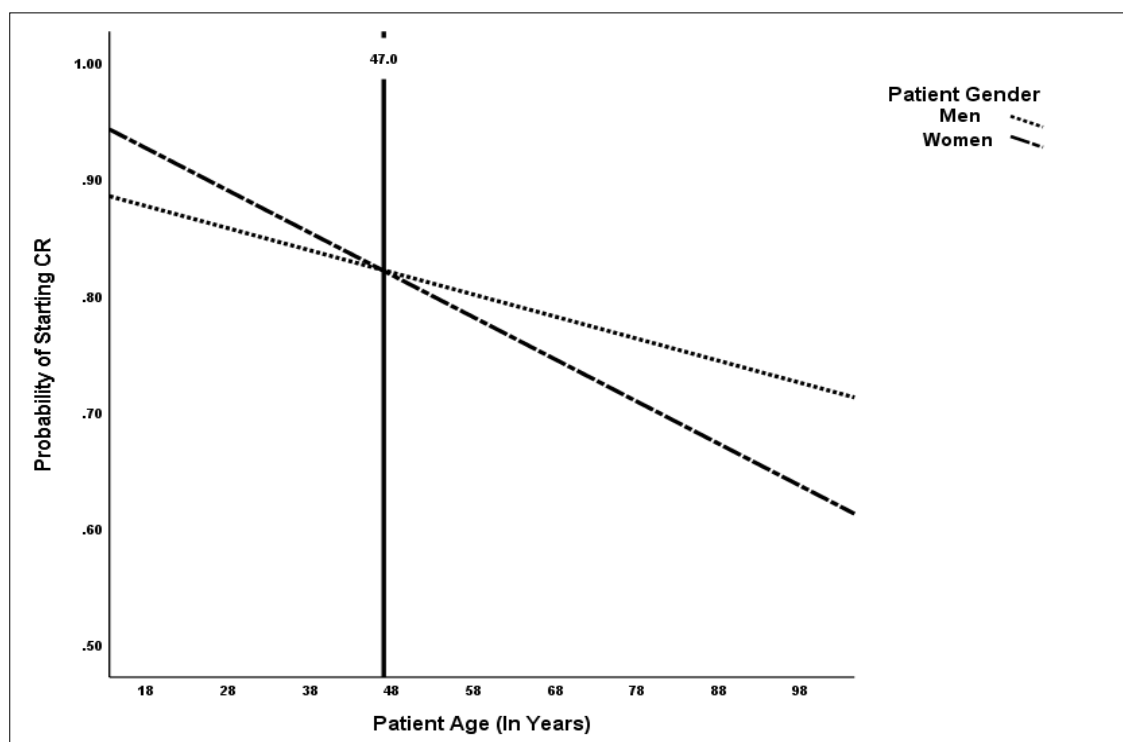
Figure 3.5 Interaction Relationship (Age*Gender) When Starting CR
CR: cardiac rehabilitation.

3.5.3.2.3 Cardiac-Event Factors

Patients post-CABG were more likely to start CR by 14.0% compared to patients post-valve surgeries (OR: 1.14, 95% CI: 1.07, 1.22) and by 13.0% times compared to patients post both CABG and valve surgeries (OR: 1.13, 95% CI: 0.81, 0.97). While the comorbidities of angina, hypertension, anxiety and depression were not significant, diabetes mellitus, family history of CVD and hyperlipidaemia were, with being diagnosed with diabetes mellitus decreased the odds of starting CR by 0.86 times (95% CI: 0.81,

0.92), while having a family history of CVD and being diagnosed with hyperlipidaemia increase the likelihood of starting CR (OR: 1.29, 95% CI: 1.21, 1.38) and (OR: 1.11, 95% CI: 1.04, 1.18) respectively. Having no history of previous cardiac events increased the odds by 1.35 times of starting CR (95% CI: 1.27, 1.43). Patients with a hospital stay of up to 6 days were more likely to start CR by 11.0% compared to patients with a hospital length of stay of ≥18 days (OR: 1.11, 95% CI: 1.03, 1.21). A confirmed joining date for the CR programme increased the odds of starting CR by 3.80 times (95% CI: 3.58, 4.02).

3.6 Discussion

Based on the literature review, 21 factors were identified as having an association with CR starting. This study aimed to assess the level of the association using national audit data and found 15 factors associated with starting CR in patients following cardiac surgeries via median sternotomy. In the light of the regression results, the prospects of the patient starting CR increase with the participants being post-CABG, waited > 6 weeks from the treatment day, being younger, male, women younger than 47 years or men older than 47 years, non-white ethnicity, had a high SES, no previous CR, and partnered. Also associated with starting CR is being diagnosed with hyperlipidaemia, having a family history of CVD, having a hospital length of stay of 6 days or less, and having a confirmed joining date. While the likelihood of starting CR decreases with diabetes mellitus and having a history of previous cardiac events. Also, based on the results, the researcher rejected the null hypothesis and accepted the experimental hypothesis that states, "Waiting time has an association with starting CR". These results were based on data collected from routine health care, strengthening its generalisability.

3.6.1 Waiting Time

Waiting time, in particular, the longer waiting time has a strong association with an increased likelihood of starting CR in patients post open heart surgeries based on data

from NACR and in agreement with findings of earlier research on non-surgical cardiac intervention (al Quait, 2018). Patients waiting > 6 weeks, as routinely advised by cardiac surgeons, were 2.55 times more likely to start CR compared who waited up to 6 weeks. When waiting time was categorised by intervals of 2 weeks (i.e., WT $\leq$ 2 weeks, 2 > WT $\leq$ 4 weeks, 4 > WT $\leq$ 6 weeks, 6 > WT $\leq$ 8 weeks, WT > 8 weeks), it shows a similar trend with the probability of starting CR increasing with time until 8 weeks. Waiting time analysed as a continuous variable also showed a positive relationship with starting CR; for every week of waiting, there was a 13.4% increased likelihood of starting CR. Most post-surgical patients who start CR tend to wait longer than 6 weeks, which suggests that clinical teams were adhering to the post surgeries guidelines that restrict early activity on the basis that it may aid in the healing of the sternum. However, this finding conflicts with the reporting of other studies that examined the influence of waiting time on starting CR. Russell et al. (2011), in a study with 599 patients, defined waiting time as the period between referral date and first CR assessment, and they reported that patients who started CR had a median waiting time of 41 days, while patients who did not start CR had a median waiting time of 58 days. Put differently, they found longer waiting time for patients who did not start CR compared to patients who started CR with OR: 0.99 (95% CI: 0.98, 0.99), i.e., for every increase in waiting time by a day, there was decreased by 1% in the likelihood for a starting CR (Russell et al., 2011). Waiting time is an issue in CR not only because it influences starting CR but also because it influences on CR outcome since there were reports that argue that the patients who start CR later than necessary would not benefit to the same extent as patients who start early. A study with 1,241 patients who underwent 3 months of CR and were assessed at the end of CR showed an improvement in body weight and exercise capacity for those starting CR early versus those starting CR later as well (Johnson et al., 2014). Furthermore, another study with 32,899 patients tested if waiting time would influence CR physical fitness, where waiting

time was measured as the period between the referral date and starting the CR programme. They describe waiting time to be shorter when it was up to 4 weeks (longer more than 4 weeks) and up to 6 weeks (longer more than 6 weeks) for non-open heart intervention and open-heart surgeries, respectively. The study found that longer waiting time was associated with a minor fitness improvement, unlike shorter waiting times where patients demonstrated optimal fitness gains (Fell, Dale and Doherty, 2016).

3.6.2 Patient Factors

Age has an inverse association with the likelihood of starting CR, i.e., as there is an increase in age, the odds of a patient starting CR decreases (OR: 0.99 95% CI: 0.98, 0.99). This finding is in accordance with (van Engen-Verheul et al., 2013), who reported a decreased rate of starting CR with older age. Turk-Adawi et al. (2014) published a similar result that links starting CR with the participant's age, where younger patients were more likely to start CR, unlike older patients. Being under the age of 70 years old increases the odds of starting CR (Smith, Harkness and Arthur, 2006). The obtained results from this study were in agreement with several studies (Worcester et al., 2004; Ratchford et al., 2004; Kotseva et al., 2013; Beauchamp et al., 2013; Dankner et al., 2015; Sumner, Grace and Doherty, 2016; Krishnamurthi et al., 2019). However, the findings disagree with other work as the cross-sectional study by Ali et al. (2012) conducted in Pakistan; they reported that for a sample of patients post-AMI, CABG and PCI, the mean age for patients started CR (151 patients) was 56.1 (SD = 10.3) years and for no starter (265 patients) was 57.2 (SD = 10.7) years with no significant difference between them (p-value = 0.32). Inspecting the age between the patients in the 2 waiting time groups ($\leq$ 6 weeks and > 6 weeks) was statistically significant, which adds to overarching BACPR and European recommendations that CR programmes need to be tailored to patient characteristics (BACPR, 2017; Piepoli et al., 2010). Older patients may have less accessibility to CR centres, tend to have more comorbidities, and may be in a health condition affecting their

exercise performance (Ratchford et al., 2004; Worcester et al., 2004; Smith, Harkness and Arthur, 2006).

Patient gender was found to influence patient participation and starting CR, with male patients having a higher probability of starting CR compared to female patients (odds ratio of 1.18, 95% CI: 1.10, 1.26), while being female is connected with decreased chances of starting CR (Jegier et al., 2011). The factor, as mentioned earlier, is supported by the reporting of several investigations (Suaya et al., 2007; Shanks, Moore and Zeller, 2007; Beauchamp et al., 2013; van Engen-Verheul et al., 2013; Nalini, 2014; Fell, Dale and Doherty, 2016). As it has been found in previous papers, men made up the majority in starting CR early or late compared to women by approximately 75% to 25% (Fell, Dale and Doherty, 2016). Gender disparities were also investigated by a meta-analysis that covered 26 observational studies with a total of 297,719 patients and found that women had a lower rate of starting CR by 36.0% compared to men (Samayoa et al., 2014). Additionally, the present study investigated the interaction between age and gender and found it significant. This means that younger women would have better odds of starting CR compared to young men from 18 years old until the age of 47; the pattern would change with older men being more likely to start CR than older women. These findings were similar to that reported in the non-surgical cardiac population (al Quait, 2018). There is the possibility of several deterrents or barriers for women starting CR, such as the accumulative effects of ageing and the high number of comorbidities, insufficient information about the benefit of CR, or believing it would be painful or unsatisfactory CR endorsement by healthcare professionals. Moreover, there were family commitments, low levels of social support, financial strains, and inadequate transportation accessibility (Supervía et al., 2017).

Patients' ethnicity coded as white comprised 88.0% of patients included in the analysis, while the other ethnicities (non-white) were 13.0%. It was found that non-white patients

had a higher likelihood of starting CR than their white ethnicity counterparts by the odds ratio of 1.11 (95% CI: 1.01, 1.21). In a cohort study with 945 patients with post-surgical and non-surgical cardiac interventions that investigated the rate of starting CR, white ethnicity (the majority of 76.0%) versus non-white was not a significant factor in starting CR after cardiac events (Roblin et al., 2004). Differentially, it was reported that white ethnicity is more likely to start CR compared to non-white patients by an odds ratio of 1.77 (95% CI: 1.13, 2.80) (Prince et al., 2014). These results were from a cohort study with 822 patients (diagnosed with stable angina, CAD, AMI, PCI, heart failure, heart valve disease, and CABG) where they investigated the ethnic differences in utilising CR on the mostly non-white population by 51.5%. In a similar study, with 590 patients with several diagnoses similar to the previous study, from 56.1% non-white population, patients who were of non-white ethnicity were less likely to start CR compared to white patients (OR = 0.66, 95% CI: 0.44, 0.97) which could be due to insufficient education about the importance of CR or inadequate health insurance (Zhang et al., 2017). Although this study's findings were inconsistent with the literature, it is necessary not to overlook that this study population was post-median sternotomy. In contrast, the other studies had both post-median sternotomy and non-invasive cardiac intervention. It may be that the non-white minorities in the UK had fewer obstacles, such as the language barriers and financial constraints for starting CR, compared to other countries.

Both partnership status and SES were reported to be associated with starting CR, as having a partner and higher SES with a higher likelihood of starting CR. Several researchers have reported that partnered patients had more probability of starting CR (Farley, Wade and Birchmore, 2003) while not partnered had more probability of not starting CR (Weingarten et al., 2011; Sumner, Grace and Doherty, 2016). This is supported by a meta-analysis that aimed to investigate the connection between starting CR and partnership status, where they report a 1.5–2 times more probability for partnered

patients to start CR (Molloy et al., 2008), and this maybe was because having a partner would increase both social and financial support that can facilitate starting CR. Patients with the highest SES had increased chances of starting CR by 67.0% (OR = 1.67, 95% CI: 1.52, 1.83), which aligns with the results of several papers (Suaya et al., 2007; Nielsen et al., 2008; Grace et al., 2008; Lemstra et al., 2013; Sumner, Grace and Doherty, 2016). In a cohort study by Lemstra et al. (2013), they examined how neighbourhoods income impacts starting CR and found that patients from low-income neighbourhoods were less likely by 1.58 times (95% CI: 1.39, 1.71) compared to high-income neighbourhoods, which could be attributed to patients from low-income neighbourhoods having insufficient knowledge about the importance of CR, social support, or transportation to CR centres (Lemstra et al., 2013).

The history of prior CR participation was investigated, and it was found that patients who attended CR previously form a low percentage compared to patients with no history of CR, and they make 4.9% and 1.8% for not starting CR and starting CR, respectively. This may explain why no previous CR attendance was associated with a higher likelihood of starting CR by 2.76 times (95% CI: 2.35, 3.24) compared to those who had prior participation. Similarly, Dunlay et al. (2009), in a prospective study and 179 patients post-AMI, reported that patients who attended CR previously were less likely to start CR by 0.26 times (95% CI: 0.12, 0.56) (Dunlay et al., 2009). However, the opposite was reported by Doolan-noble et al., as the New Zealand CR audit found that having a history of attending CR increases the likelihood of starting CR by 2.38 times (95% CI: 1.46, 3.91) (Doolan-Noble et al., 2004).

3.6.3 Cardiac-Event Factors

The influence of treatment type or diagnosis on starting CR was investigated in several studies. When compared to cardiac diagnosis or non-open heart interventions, it was documented that there was a strong association with a high probability of starting CR in

a study that included both CABG surgery and valve surgeries (van Engen-Verheul et al., 2013) or only CABG surgery (Suaya et al., 2007; Bethell et al., 2008; Turk-Adawi et al., 2014; Sumner, Grace and Doherty, 2016). In the Netherlands, a cohort study with 35,752 patients investigated various types of factors (including treatment types) associated with the probability of starting CR, where they reported more likelihood for post-CABG by 2.76 times and post-valve surgeries by 1.78 times compared to acute PCI (van Engen-Verheul et al., 2013). The chances for both groups for patients post-CABG or post-AMI and CABG had a 3.5 times probability of starting CR compared to AMI, according to Suaya et al. (2007) cohort study with 267,427 patients conducted using Medicare's National Claims History File on the USA. In another cohort study from the USA with 6,874 patients, the odds ratio for CABG to start CR was 1.72 (Turk-Adawi et al., 2014). From the UK, based on collected data from questionnaires sent to CR centres in England, (Bethell et al., 2008) reported the CR starting rate for CABG to be the highest among other cardiac conditions at 66.0%, while Sumner, Grace and Doherty (2016) found CABG 1.64 times better chance to start CR. There were several theories as to why patients post certain treatment types, besides others, had more access to CR and subsequently started CR. It could be due to the existence of well-established guidelines for specific treatment types like CABG but insufficient for the others (van Engen-Verheul et al., 2013). Among different countries, there is a variety in the standers for being eligible for CR and qualifying for health coverage (Suaya et al., 2007; Bethell et al., 2008; van Engen-Verheul et al., 2013). There was also the reason of different potential complications, both physical and psychological, that could result from cardiac surgeries, which could be tackled by CR (Sumner, Grace and Doherty, 2016).

Having a history of previous cardiac events, the number of comorbidities and their association with starting CR has been the subject of investigations in several studies. This study has found that the factors of a positive history of previous cardiac events, no

diabetes mellitus, family history of CVD and hyperlipidaemia were significantly associated with increasing the probability of starting CR. At the same time, angina, hypertension, anxiety, depression, and the number of comorbidities were not significant. While being diagnosed with diabetes mellitus has a significant association with not starting CR (Weingarten et al., 2011; van Engen-Verheul et al., 2013; Turk-Adawi et al., 2014; Sumner, Grace and Doherty, 2016), it was also reported not being significant (Farley, Wade and Birchmore, 2003; Ratchford et al., 2004; Grace et al., 2008). In this study, patients with diabetes mellitus were less likely to start CR by 0.86 (95% CI: 0.81, 0.92), and this could be due to the coexisting physical and psychological health issues that act as barriers to starting CR. Both family history of CVD and hyperlipidaemia were found not significant (Farley, Wade and Birchmore, 2003; Grace et al., 2008), while Ratchford et al. (2004) found hyperlipidaemia to be significant for not starting CR and a history of previous cardiac events not significant. A family history of CVD is associated with a 29.0% likelihood of starting CR, and being diagnosed with hyperlipidaemia increases the likelihood of starting CR by 11.0%. Considering that a family history of CVD and hyperlipidaemia were risk factors for cardiac disease (Lloyd-Jones et al., 2004; Nelson, 2013), it would be beneficial to control them with CR. The association between having a higher number of comorbidities and not starting CR was reported to be significant (Weingarten et al., 2011), and this contrasts with (Sumner, Grace and Doherty, 2016) as they found it to be nonsignificant, additionally found that patients with anxiety to be more likely to start CR, but depression was not significant.

In the current study, the median hospital length of stay was 9 days, with the 25th percentile being 6 days; staying in the hospital from 7 to 9 days was not a significant factor for starting CR; however, as the hospital length of stay increased to more than the median to 75th percentile (17 days) or more the prospect of starting CR decreases by 0.92 and 0.90 times. This aligns or concurs with (Jegier et al., 2011), whose cohort study and 82 patients

post open heart surgeries reported that hospital length of stay is 1.17 times for not starting CR. More prolonged hospital stay is associated with postoperative complications that could limit patients from starting CR (Peterson et al., 2002; Mahesh et al., 2012; Yu et al., 2016). As shown in previous studies (al Quait, 2018), patients with a confirmed joining date were 3.60 times more likely to start CR. This study shows that the percentage of patients with a confirmed joining date who did not start CR form 20.0% compared to 80.0% who started CR, and this highlights the importance of ensuring all CR eligible patients had received a confirmed joining date.

3.7 Strengths and Limitations

The observational cohort study, based on routine practice data, has the advantage of being more comparable (i.e. similar in terms of socio-demographic characteristics and health profiles) to the type of patients that were seen on a daily basis by health care services meaning that this study's findings on the influence of waiting time on starting CR were generalisable to the CABG and valve surgery patient population. Also, it reflects the actual population as they do not limit or exclude patients based on specific variables such as age, gender, or comorbidities. However, an observational cohort study, like any study design, has issues that need to be addressed and treated, such as the issue of missing data or data errors outside the theoretical threshold when creating variables, e.g., waiting time. In addition, while this research managed to test the association of 21 variables with starting CR, few variables were mentioned in the literature for association with CR starting, but they were not collected by the NACR, e.g., travel time to CR centre and language. These additional variables and modifications could be recommended to the NACR to be included for continued monitoring, audit, and future research.

3.8 Conclusion

This study has shown that longer waiting time of > 6 weeks was significantly associated with the increased likelihood of starting CR in a population of post-median sternotomy. The additional factors associated with starting CR were being post-CABG, younger, a male, a male with age above or a female below 47 years old. Moreover, non-white ethnicity, high SES, partnered and no previous CR. In addition, having a family history of CVD and previous cardiac events, being diagnosed with hyperlipidaemia but not diabetes mellitus, having a hospital length of stay of ≤ 6 days and with a confirmed joining date. Therefore, CR programmes should try to align or tailor the CR offer with patient characteristics known to increase the likelihood of starting CR early.

CHAPTER 4 Completing CR for Post-Surgical Cardiac Rehabilitation Patients

4.1 Background

The intervention of CR is interdisciplinary and evidence-based for patients with CVD and post-open-heart surgeries, with a number of essential elements such as exercise training, psychosocial care, and the management of risk factors (BACPR, 2017). CR is recognised as an effective approach to tackling the increasing rates of cardiac mortality and morbidity as well as being cost-effective (Dalal, Doherty and Taylor, 2015; Shields et al., 2018). However, there are reports in the literature of CR being underutilised (NACR 2019) and around 20.0% to 30.0% drop out from the programme and failing to complete CR (Turk-Adawi et al., 2013; Ruano-Ravina et al., 2016; Oosenbrug et al., 2016).

When investigating CR utilisation, a meta-analysis of 11 studies (and samples from Canada, Iran, Ireland, New Zealand, the UK, and the USA) by Turk-Adawi and Grace (2015) reported a considerable variation in the proportion of CR non-completers, ranging from 12.0% to 82.0%. Furthermore, an observational study conducted in Canada of 5,886 patients who underwent CR reported that only 2,900 patients (49.3%) completed CR, while 554 patients did not complete CR, with the rest failing to start CR. They explored the relationship between mortality and hospitalisation with completing CR and found that CR completers had better survival and lower risk of hospitalisation when compared to CR non-completers (Martin et al., 2012).

Based on the above, it is important to identify modifiable and unmodifiable factors/barriers associated with CR utilisation that need to be overcome to deliver a more tailored and targeted CR programme that has a higher completion rate. Therefore, while this research literature review (chapter 1) was conducted with emphasis on waiting time and various CR outcomes, it was also carried out with an inclusive approach to identify

factors that would be associated with CR utilisations, including CR completion. The meaning of CR completion is that patients attend the assessment at the end of the programme after attending some of the sessions at a minimum (Santiago de Araújo Pio et al., 2019).

From the literature review, Marzolini et al. (2015) published research where they reported, in a post-cardiac surgery population, which waiting time was negatively associated with CR completion, i.e., the longer the patients wait to start CR, the more likely they would not complete and drop out from the rehabilitation programme. Furthermore, the described negative association with completing CR extends to affect the patient outcomes following CR, for instance, smaller gains in aerobic capacity (Marzolini et al., 2015).

The SheppHeartCABG randomised controlled trial represents a unique version of early CR in that it was delivered for 4 weeks and started 1 day before surgery; they report no evidence of a difference in the primary outcomes measure of 6MWT between the interventional group (comprehensive early CR) and control group (usual care) (Højskov et al., 2019). Meanwhile, most CR in the UK starts following surgery and continues as an outpatient service for 8 to 12 weeks (BACPR, 2017). The SheppHeartCABG included several other secondary outcomes and 6MWT, which, as previously stated, maybe was hindered by the ceiling effect (Frost et al., 2005). The results of this study could arguably be explained due to the issue of the participants' low actual utilisation of the CR programme, which consequently resulted in low CR outcomes.

Although SheppHeartCABG has addressed the question about early inpatient CR, the influence of waiting time remains unknown in respect of CR outcomes. On this basis, it remains important to address this gap in the literature and clinical practice by investigating the extent to which waiting time informs CR completion (Parker et al., 2011; Fell, Dale and Doherty, 2016). In addition to waiting time as a factor that could have an

association with CR completion, several other possible factors are patient-related (e.g., age and gender), cardiac-events related (e.g., comorbidities), CR assessment-related (e.g., obesity, smoking) and CR delivery related (Ruano-Ravina et al., 2016; Oosenbrug et al., 2016; al Quait, 2018). This study aims to determine the level of association between waiting time and CR completion for patients following CABG, post-valve surgeries and combined CABG and valve surgeries using NACR data.

4.2 Study Objective

The study objective is to design, conduct, analyse and interpret the findings from an observational study using national audit data for patients following CABG surgery/cardiac valve surgery/or both to determine the level of association between waiting time and completing CR. The overarching research question this chapter will address is what factors are associated with waiting time and completion in patients following coronary bypass graft surgery, post-valve surgeries and combined CABG and valve surgeries?

The study's nondirectional (a two-tail test) hypotheses would be as follow:

H0 (null): Waiting time has no association with completing CR.

H1 (experimental): Waiting time has an association with completing CR.

4.3 Methods

4.3.1 Study Design

This retrospective observational study included all patients 18 years and older as well as both male and female patients post heart surgeries via median sternotomy, particularly CABG and valvular heart surgeries and combined with no exclusion criteria. The NACR database was used as a data source for the period from January 2013 to October 2019. The checklist of the STROBE Statement was used when reporting this study (von Elm et al., 2014) (Appendix I).

4.3.2 Data Sources

NACR was founded to monitor and report on the quality and outcomes of CR services provided to patients with CVD through their collaboration with NHS Digital, which collects and manages patient-level data before sending it to the NACR in an anonymised format. The data type resides in 1 of 4 categories, patient, initiating event, assessment, and rehabilitation. Under the patient category would be personal information (such as gender, partnership status, and ethnic group) for initiating event would be information about patients' cardiac events/surgery (such as names of initiating event, treatment date, and discharge date), for assessment category would be patients measurements during CR assessments (e.g., body mass index (BMI) kg/m^2, smoking, alcohol consumption) as for rehabilitation category would be data regarding the delivery of CR service (e.g., multidisciplinary team, BACPR certified programme). The data source of this study was the CR programmes' information obtained by NACR for the 7 years between 2013 and 2019. This period was chosen as it reflects modern service provision and represents a period when data entry quality achieved higher quality status. Before 2013, there were a few known issues with data thresholds leading to potential data entry errors in weight and BMI.

4.3.3 Study Variables

This study analysis involved assessing the probability of the outcomes of completing CR (No or Yes) by using binary logistic regression analysis and 35 independent variables. Besides completing CR and waiting time, the rest of the variables were classified into 4 categories according to their types in the NACR database: patient, cardiac event, pre-CR assessment, and CR delivery factors. Table 4.1 describes all the updated variables (waiting time, age- mean centring) and newly introduced variables, i.e., completing CR, pre-CR assessment, and CR delivery factors. In addition, patient factors and cardiac-event factors were described in chapter 3, Table 3.1.

Table 4.1 The Study Variables – Part 2

The Variable	Description
Study Outcome	
Completing CR	NACR data would classify a patients as completing CR if they have started CR, attended some of the CR sessions and attended post-CR assessment. Completing CR is a binary variable (No, Yes).
Waiting Time	

Waiting time	Waiting time between first CR assessment date/or referral date and the starting CR date. After the removal of unusual data (less than a day or more than 365 days) then, 3 variables were created:
	1) Binary categories (≤ 6 weeks WT, > 6 weeks WT).
	2) Multicategories variable with an increased 2-week interval
	   ▪ WT ≤ 2 weeks.
	   ▪ $2 > $ WT ≤ 4 weeks.
	   ▪ $4 > $ WT ≤ 6 weeks
	   ▪ $6 > $ WT ≤ 8 weeks.
	   ▪ WT > 8 weeks.
	3) Continuous variable (WT in weeks).

Patient Factors	
Age (Mean centring)	A continuous variable recoded the age variable (expressing patient age in years) into an age-centring variable by subtracting the population's age mean (66.6) from each patient's age. The population for this chapter is 68,580 patients who started CR.
Cardiac-Event Factors	

Hospital length of stay	This is a categorical variable where the period between the date of hospital admission and the date of hospital discharge was calculated, and then it was classified according to percentiles based where the percentile 25 = 6 days, percentile 50 (median) = 9 and percentile 75 = 16:
	   ▪ ≤ 6 days (i.e., from 1 to 25th percentile).
	   ▪ 7-9 days (i.e., more than 25th percentile to 50th percentile).
	   ▪ 10-16 days (i.e., more than 50th percentile to 75th percentile).
	   ▪ ≥ 17 days (i.e., more than 75th percentile).

Pre-CR Assessment Factors	
HADS-Anxiety	Patients' scores on the Anxiety component of HADS were classified into 2 categories (Normal, Borderline abnormal/Clinically Anxious), where Normal entails scoring ≤ 7 and Borderline abnormal/Clinically Anxious when scoring ≥ 8.

Table 4.1 The Study Variables – Part 2

The Variable	Description
HADS-Depression	Patients' scores on the Depression component of HADS were classified into 2 categories (Normal, Borderline abnormal/ Clinically Depressed), where Normal entails scoring ≤ 7 and Borderline abnormal/Clinically Anxious when scoring ≥ 8.
Social Support	Patients' responses to the social support component of the Dartmouth Coop Functional Assessment Chart were classified into 2 categories (No, Yes). Scoring for social support is a 1-5 scale: 1 = Yes, as much as I wanted 2 = Yes, quite a bit 3 = Yes, some 4 = Yes, a little 5 = No, not at all Therefore 1-4 would be classified as Yes and 5 as NO.
Employment	Patients' employment status was classified into 3 categories: ▪ Employed ▪ Unemployed ▪ Retired
BMI	Patient weight is classified according to their BMI, which is calculated by weight (kg)/ and height (m^2). There are 2 categories (< 30 kg/m^2, ≥ 30 kg/m^2) where is ≥ 30 kg/m^2 considered obese, as stated in NICE guidelines (NICE, 2015).
Physical activity (150 min/week)	Patient's responses were classified into 2 categories (No, Yes) to the question, "Do you take regular physical activity of at least 30 minutes duration on average 5 times a week (equivalent to 150 minutes over 7 days)?".
Smoking	The patient's response to if he\she is a smoker or not was classified into 2 categories (No, Yes).
Alcohol consumption	Patients' alcohol consumption was classified into 2 categories (> 14 units per week, ≤ 14 units/week), where ≤ 14 units/week is the recommended level of alcohol drinking for both men and women in the UK (Department of Health, 2016).
CR delivery Factors	
CR delivery mode	CR mode delivery was classified into 2 categories (Supervised, Self-Delivered).
Referral Source	The type of healthcare setting issued the CR referral was classified into 2 categories (Private Hospital, GP/NHS Trust).

Table 4.1 The Study Variables – Part 2

The Variable	Description
Referring health professional	The healthcare professional that made the CR referral was classified into 3 categories: ▪ consultant/cardiac nurse. ▪ GP/primary care nurse. ▪ Other.
Multidisciplinary team	The CR programmes run by a multidisciplinary team were classified into 2 categories (No, Yes).
BACPR certified programme	If the CR Programme was BACPR certified, it was classified into 2 categories (No, Yes).

CR: cardiac rehabilitation. BMI: body mass index. HADS: Hospital Anxiety and Depression Scale. NICE: National Institute for Health and Care Excellence. GP: general practitioner. NHS: National Health Service. BACPR: British Association for Cardiovascular Prevention and Rehabilitation.

4.4 Data Analysis

The categorical variables were presented using counts and percentages, while continuous variables were presented using mean and SD (in addition to counts and percentages). To compare variables, chi-square tests and independent samples t-tests were computed for categorical and continuous variables correspondingly. The factors included in this study were found to be associated with CR completion, according to the literature. These factors were collected routinely by NACR; therefore, they were examined for inclusion in the study under the condition that the missing data percentage was no more than 50.0%, which none of them was. At the same time, 6 factors were mentioned in the literature to be associated with completing CR, but they were not included in this study since they were not obtained by NACR. The factors were the distance between the patient's residence/place of employment and the CR centre, cardioprotective medications, insurance coverage, left ventricular ejection fraction measurement, illness perception questionnaire, and education.

Binomial logistic regression analysis was used to test the association between the identified independent factors and the dichotomous outcome of CR completion using the

backward selection method. The model was built in a hierarchical model of 6 blocks: block 1 (treatment type, waiting time), block 2 (age (mean centred), gender, age*gender, ethnicity, partnership status, SES), block 3 (hospital length of stay, previous CR, angina, diabetes mellitus, hypertension, anxiety, depression, family history of CVD, hyperlipidaemia, number of comorbidities, previous CABG, a diagnosis of ≥ 2 cardiac events, previous cardiac events), block 4 (confirmed joining date, smoking, BMI, physical activity (150 min/week), employment, HADS-Anxiety, HADS-Depression, social support, alcohol consumption), block 5 (CR delivery mode, referring health professional, referral source), and, block 6 (multidisciplinary team and BACPR certified programme). Each model was evaluated, and its assumption was assessed, as mentioned in the methodology, chapter 2, section 2.4.1. All the statistical tests would be considered significant if the p-value < 0.05 and adjusted for multiple chi-square tests using Bonferroni correction to 0.002.

4.5 Results

4.5.1 Descriptive and Inferential Statistics
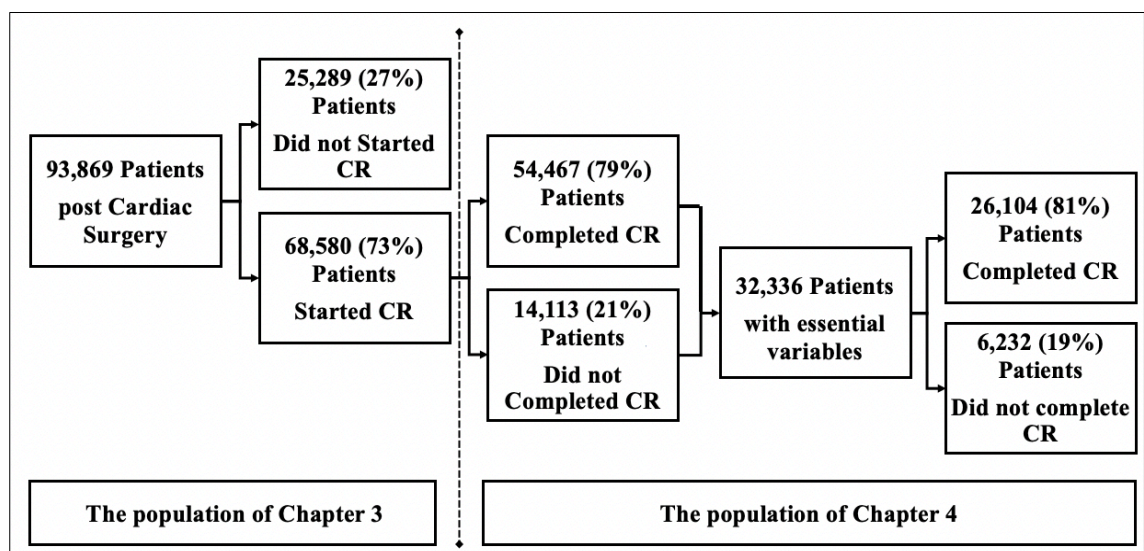
Figure 4.1 Flow Chart of the Study Sample

CR: cardiac rehabilitation.

According to the NACR database, there were 93,869 patients who underwent one form of cardiac surgery (CABG, valve surgeries and combined CABG and valve surgeries). This was over 7 years, from January 2013 to October 2019. From the number mentioned above, 68,580 patients had started CR, with the majority, 79.0% (54,467 patients), having completed CR compared to 21.0% (14,113 patients) who did not complete CR (see Figure 4.1). There are 32,336 cases that had their complete essential information available for analysis: the patient factors (age, gender, ethnicity, SES, partnership status, previous CR) in addition to treatment types and waiting time.

Descriptive and inferential statistics were used to detail and examine the association between CR completion and waiting time, patient factors, cardiac-event factors, pre-CR assessment factors and CR delivery factors.

4.5.1.1 Waiting Time

The distribution of the patients between waiting times at each CR completion outcome was similar; however, more patients completed CR (47,092 patients) compared to those who did not complete CR (11,821 patients) (see Table 4.2). The chi-square test to assess the association between waiting time and CR completion was a nonsignificant χ^2 (1) = 0.8, p-value = 0.355.

Table 4.2 Comparison of Waiting Time With Completing CR Variable

Waiting time Factor		Completed CR NO	Completed CR Yes	Chi-square	df	p-value*
		Count (%)	Count (%)			
Waiting time	**≤ 6 weeks WT**	6,498 (55.0)	26,109 (55.4)			
	> 6 weeks WT	5,323 (45.0)	20,983 (44.6)	0.8	1	0.355
	Total	11,821	47,092			

* Significant after Bonferroni correction for multiple testing if p-value < 0.002.
%: percentage. CR: cardiac rehabilitation. WT: waiting time. Df: degrees of freedom.

4.5.1.2 Patient Factors

The patient factors included age, gender, ethnicity, partnership status, SES, and history of previous CR, as shown in Table 4.3, indicating that in all the factors, there were more CR completers compared to CR non-completers. While the mean age for the whole study population was 66.6 (SD = 11) years, it was 67.0 (SD = 11) years for patients who completed CR, an age increase of 2 years, compared to 65.0 (SD = 12) years for patients who did not complete CR. The independent t-test showed a significant difference between the age means for the completed CR two groups, t (68,578) = −14.7. Men made up the majority of patients compared to women by 73.3% and 76.8% for the group of not completed CR and completed CR, respectively. There was an association between gender and completing CR as the chi-square test was significant χ^2 (1) = 75.3. The ethnicity presentation revealed it was predominantly white ethnic in both CR completion groups with a significant association χ^2 (1) = 17.5. Most of the patients were partnered, where 74.8% of them did not complete the CR, while 80.3% of partnered patients completed CR. For the group who did not complete CR, patients were distributed roughly the same among the 5 SES, ranging from 18.3% at the first quintile (most-deprived) and 21.7% at the fifth quintile (least-deprived). Meanwhile, for patients who completed CR, as the SES increases, more patients would complete CR, with 5,354 (12.2%) coming from the most deprived area (first quintile) compared to 12,243 (27.8%) from the least deprived areas (fifth quintile). The association was significant between SES and the status of completing CR χ^2 (4) = 450.4. There was also a significant association between whether patients did or did not receive CR previously and completing CR, as most patients do not have a history of CR.

Table 4.3 Cross-Tabulations for Patient Factors and Completing CR Variable

Patient Factors		Completed CR (NO)		Completed CR (YES)		t-value	df	p-value *
		Count (%)	Mean (SD)	Count (%)	Mean (SD)			
Age (In years)		14,113 (20.6)	65.0 (12)	54,467 (79.4)	67.0 (11)	−14.7	68, 578	< 0.001
Patient Factors		**Count (%)**		**Count (%)**		Chi-square	df	p-value **
Gender	Male	10,199 (73.3)		40,998 (76.8)		75.3	1	< 0.001
	Female	3,711 (26.7)		12,354 (23.2)				
Ethnicity	White	10,318 (85.8)		40,240 (87.3)		17.5	1	< 0.001
	Non-white	1,702 (14.2)		5,863 (12.7)				
Partnership status	Partnered	7,178 (74.8)		30,630 (80.3)		140.1	1	< 0.001
	Not partnered	2,419 (25.2)		7,523 (19.7)				
SES	First quintile	2,082 (18.3)		5,354 (12.2)		450.4	4	< 0.001
	Second quintile	2,158 (18.9)		7,086 (16.1)				
	Third quintile	2,294 (20.1)		8,896 (20.2)				
	Fourth quintile	2,392 (21.0)		10,454 (23.7)				
	Fifth quintile	2,478 (21.7)		12,243 (27.8)				
Previous CR	Previous CR	313 (2.2)		908 (1.7)		19.4	1	< 0.001
	No previous CR	13,800 (97.8)		53,559 (98.3)				

* Significant if p-value < 0.05. ** Significant after Bonferroni correction for multiple testing if p-value < 0.002.

%: percentage. CR: cardiac rehabilitation. SES: socioeconomic status. SD: standard deviations. df: degrees of freedom.

4.5.1.3 Cardiac-Event Factors

Fourteen cardiac-event factors were presented in Table 4.4. There was a significant association between completing CR and treatment type χ^2 (1) = 39.4. Patients post-CABG who completed CR made up slightly more than half (57.8%) of the population, followed

by patients post-valve surgeries (31.4%), with patients post combined CABG and valve surgeries making up 10.8%. The association was tested between completing CR outcomes and the comorbidities of angina, diabetes mellitus, hypertension, anxiety, depression, family history of CVD, and hyperlipidaemia. It was significant for diabetes mellitus, anxiety, and depression but not for the remainder of the factors. For each one of the comorbidities, patients who were not diagnosed were more than those who did, except for those diagnosed with hypertension, who made up 53.0%. The distribution of patients according to the number of comorbidities showed, among CR completers, that a small percentage did not have any comorbidity 3.9% (1,567 patients), the following having ≥ 3 comorbidities 45.9% (18,315 patients) and finally, those with 1-2 comorbidities made up 50.0% (20,018 patients). The association between completing CR and the number of comorbidities was significant, $\chi^2 (2) = 52.485$. There was a nonsignificant association between completing CR and having a prior history of CABG (p-value = 0.457) nor being diagnosed with ≥ 2 cardiac events (i.e., CABG, heart valve surgeries, AMI, or PCI) (p-value = 0.466).

Patients with no previous cardiac events formed 63.6% and 65.9% for not completing and completing CR, respectively, with a significant association between them. As the median hospital length of stay was 9 days, the proportions of patients showed that the majority were hospitalised for up to 9 days, or they would experience prolonged hospitalisation, i.e., ≥ 17 days. There was a significant association between hospital length of stay on the status of completing CR (No, Yes) $\chi^2 (3) = 69.6$. As most patients had a confirmed joining date for CR, there was a significant relationship between it and completing CR, $\chi^2(1) = 16.9$.

Table 4.4 Cross-Tabulations for Cardiac-Event Factors and Completing CR Variable

Cardiac-Event Factors		Completed CR (NO) Count (%)	Completed CR (YES) Count (%)	Chi-square	df	p-value*
Treatment type	CABG	7,788 (55.2)	31,487 (57.8)	39.4	2	< 0.001
	Valve surgeries	4,811 (34.1)	17,089 (31.4)			
	CABG/valve	1,514 (10.7)	5,891 (10.8)			
Angina	No	8,665 (82.6)	32,601 (81.7)	4.2	1	< 0.001
	Yes	1,829 (17.4)	7,299 (18.3)			
Diabetes mellitus	No	7,540 (71.9)	30,699 (76.9)	117.6	1	< 0.001
	Yes	2,954 (28.1)	9,201 (23.1)			
Hypertension	No	4,913 (46.8)	18,431 (46.2)	1.3	1	0.254
	Yes	5,581 (53.2)	21,469 (53.8)			
Anxiety	No	9,822 (93.6)	38,038 (95.3)	52.5	1	< 0.001
	Yes	672 (6.4)	1,862 (4.7)			
Depression	No	9,669 (92.1)	37,865 (94.9)	118.3	1	< 0.001
	Yes	825 (7.9)	2,035 (5.1)			
Family history of CVD	No	7,826 (74.6)	29,461 (73.8)	2.4	1	0.125
	Yes	2,668 (25.4)	10,439 (26.2)			
Hyperlipidaemia	No	6,738 (64.2)	25,438 (63.8)	0.7	1	0.389
	Yes	3,756 (35.8)	14,462 (36.2)			
Number of comorbidities	No comorbidity	354 (3.4)	1,567 (3.9)	52.5	2	< 0.001
	1-2 comorbidities	4,914 (46.8)	20,018 (50.2)			
	≥ 3 comorbidities	5,226 (49.8)	18,315 (45.9)			
Previous CABG	No	6,584 (94)	24,481 (94.3)	0.6	1	0.457
	Yes	417 (6)	1,486 (5.7)			
A diagnosis of ≥ 2 cardiac events	CABG and\or valve	11,926 (84.5)	46,244 (84.9)	2.6	3	0.466
	CABG and\or valve plus AMI	1,985 (14.1)	7,520 (13.8)			
	CABG and\or valve plus PCI	64 (0.5)	214 (0.4)			
	CABG and\or valve plus AMI + PCI	138 (1)	489 (0.9)			
Previous cardiac events	No	8,977 (63.6)	35,893 (65.9)	26	1	< 0.001
	Yes	5,136 (36.4)	18,574 (34.1)			
Hospital length of stay	≤ 6 days	3,061 (26.4)	13,559 (29.8)	69.6	3	< 0.001
	7-9 days	2,935 (25.3)	11,723 (25.8)			
	10-16 days	2,592 (22.4)	9,236 (20.3)			
	≥ 17 days	3,003 (25.9)	10,931 (24.1)			
Confirmed joining date	No	3,861 (27.4)	13,972 (25.7)	16.9	1	< 0.001
	Yes	10,252 (72.6)	40,495 (74.3)			

* Significant after Bonferroni correction for multiple testing if p-value < 0.002.
%: percentage. CR: cardiac rehabilitation. CABG: coronary artery bypass grafting. CVD: cardiovascular disease. AMI: acute myocardial infarction. PCI: percutaneous coronary intervention. df: degrees of freedom.

4.5.1.4 Pre-CR Assessment Factors

During the pre-CR assessment, 9 components were measured and included in this study (see Table 4.5). Most patients who answered the HADS questionnaire resided in the normal range for anxiety and depression (scoring <8); also, there was a significant relationship between the results of HADS and completing CR. Most patients who answered the social support domain at Dartmouth Coop Functional Assessment Chart said yes when asked about the availability of someone if help was required making 93.4% and 94.7% of CR completers and CR non-completers, respectively. The association between completing CR and social support was significant χ^2 (1) = 16.3. For not completing CR, the highest percentage of employment status was made by retired patients (55.9%), then employed (24.6%), and the lowest by unemployed (19.5%).

There was also a significant relationship between employment status and completing CR, χ^2 (1) = 117.2. There was a significant association between BMI and completing CR, with most patients considered not obese with a BMI less than 30 kg/m^2. While 61.4% of patients who did not complete CR said they were not physically active, this percentage dropped for those who completed CR to 54.2%, with 45.8% practising regular physical activity (150 min/week). Given that these were post-surgical patients, there was a small but significant number still smoking in the no CR group (6%) and yes CR group (2%). There was a significant relationship (χ^2 (1) = 270.3) between being a smoker or not and completing CR or not. There was no association (p-value = 0.176) between alcohol consumption and completing CR, as most patients reported they drink alcohol within 14 units per week.

Table 4.5 Cross-Tabulations for Pre-CR Assessment Factors and Completing CR Variable

Pre-CR assessment Factors		Completed CR (NO) Count (%)	Completed CR (YES) Count (%)	Chi-square	df	p-value*
HADS-Anxiety	Normal	4,889 (72.0)	27,343 (78.4)	134.3	1	< 0.001
	Borderline/clinical	1,903 (28.0)	7,527 (21.6.0)			
HADS-Depression	Normal	5,048 (74.4)	28,528 (81.8)	203.6	1	< 0.001
	Borderline/clinical	1,741 (25.6)	6,331 (18.2)			
Social support	No	437 (6.6)	1,736 (5.3)	16.3	1	< 0.001
	Yes	6,216 (93.4)	30,865 (94.7)			
Employment	Employed	1,840 (24.6)	8,512 (24.1)	117.2	2	< 0.001
	Unemployed	1,456 (19.5)	5,218 (14.8)			
	Retired	4,174 (55.9)	21,597 (61.1)			
BMI	< 30 kg/m^2	6,177 (68.7)	30,271 (74)	104.3	1	< 0.001
	≥ 30 kg/m^2	2,816 (31.3)	10,654 (26)			
Physical activity (150 min/week)	No	4,757 (61.4)	19,185 (54.2)	134.3	1	< 0.001
	Yes	2,990 (38.6)	16,225 (45.8)			
Smoking	No	9,018 (94.3)	41,423 (97.5)	270.3	1	< 0.001
	Yes	550 (5.7)	1,070 (2.5)			
Alcohol consumption	> 14 units per week	861 (12.7)	4,095 (13.3)	1.8	1	0.176
	≤ 14 units per week	5,925 (87.3)	26,689 (86.7)			

* Significant after Bonferroni correction for multiple testing if p-value < 0.002.
%: percentage. CR: cardiac rehabilitation. BMI: body mass index. HADS: Hospital Anxiety and Depression Scale. df: degrees of freedom.

4.5.1.5 CR Delivery Factors

The last 5 variables were presented in Table 4.6 under the classification of CR delivery factors. Only the variables of CR delivery mode and referring health professional had a significant association with completed CR, unlike referral source (p-value = 0.136), multidisciplinary team (p-value = 0.176) and BACPR certified programme (p-value = 0.437). There was a preference for supervised CR as a mode of delivery among most CR completers. Most CR referrals were made by a cardiac consultant/nurse and from an NHS trust or GP as a referral source. While the majority of CR programmes were not BACPR certified by 60.0%, two-thirds of CR programmes were run by multidisciplinary teams.

Table 4.6 Cross-Tabulations for CR Delivery Factors and Completing CR Variable

CR delivery Factors		Completed CR (NO) Count (%)	Completed CR (YES) Count (%)	Chi-square	df	p-value*
CR delivery mode	Supervised Delivery	6,509 (76.0)	34,325 (79.3)	45.7	1	< 0.001
	Self-Delivered CR	2,056 (24.0)	8,978 (20.7)			
Referral Source	Private Hospital	385 (4.2)	1,543 (4.6)	2.2	1	0.136
	GP/NHS trust	8,688 (95.8)	31,926 (95.4)			
Referring health professional	Consultant/cardiac nurse	10,865 (88.0)	39,313 (85.4)	52.2	2	< 0.001
	GP/primary care nurse	237 (1.9)	1,069 (2.3)			
	Others	1,249 (10.1)	5,639 (12.3)			
Multidisciplinary team	No	3,141 (22.3)	12,780 (23.5)	9.2	1	< 0.001
	yes	10,972 (77.7)	41,687 (76.5)			
BACPR certified programme	No	8,521 (60.4)	33,081 (60.7)	0.6	1	0.437
	yes	5,592 (39.6)	21,386 (39.3)			

* Significant after Bonferroni correction for multiple testing if p-value < 0.002
%: percentage. CR: cardiac rehabilitation. GP: general practitioner. NHS: National Health Service.
BACPR: British Association for Cardiovascular Prevention and Rehabilitation. df: degrees of freedom.

4.5.2 Dealing With Missing Data

The cases included in the logistic regression analysis were for patients with complete essential information: patient factors (age, gender, ethnicity, SES, partnership status, previous CR) in addition to treatment types and waiting time. In the NACR database, there were 32,336 cases with complete essential variables; meanwhile, descriptive statistics showed they had 21 other variables with missing data that ranged from 8.56% to 45.41% (Appendix J).

Table 4.7 Comparing the Patients Distribution Between Original Data and Imputed Data

Factors Name	Factors Categories	Original Data		Imputed Data	
		Completed CR		Completed CR	
		No	Yes	No	Yes
		Count (%)	Count (%)	Count (%)	Count (%)
SES	First quintile	2,082 (18.3)	5,354 (12.2)	11,330 (16.5)	31,372 (10.9)
	Second quintile	2,158 (18.9)	7,086 (16.1)	11,924 (17.4)	43,791 (15.3)
	Third quintile	2,294 (20.1)	8,896 (20.2)	13,871 (20.2)	57,002 (19.9)
	Fourth quintile	2,392 (21)	10,454 (23.7)	14,476 (21.1)	68,222 (23.8)
	Fifth quintile	2,478 (21.7)	12,243 (27.8)	16,951 (24.7)	86,757 (30.2)
Diabetes mellitus	No	7,540 (71.9)	30,699 (76.9)	47,557 (70.6)	209,622 (74.4)
	Yes	2,954 (28.1)	9,201 (23.1)	19,777 (29.4)	72,237 (25.6)
Alcohol consumption	> 14 units per week	861 (12.7)	4,095 (13.3)	8,532 (13.0)	37,678 (13.6)
	≤ 14 units per week	5,925 (87.3)	26,689 (86.7)	57,315 (87.0)	239,508 (86.4)

%: percentage. CR: cardiac rehabilitation. SES: socioeconomic status.

Little's MCAR was $\chi^2(2) = 1.5$, p-value = 0.468, which means this study's missing data were missing completely at random. Multiple imputations were applied as it had been recommended as a method to handle missing data (Schafer and Graham, 2002; Sterne et al., 2009) with 10 imputed data sets. The imputed data was checked for representing the distribution of patients between the two completing CR similarly to the original data by comparing 3 variables (Nguyen, Carlin and Lee, 2017). The proportions of patients among the variables of SES (patient factor), diabetes mellitus (cardiac-related factor), and alcohol consumption (pre-CR assessment factor) were similar, suggesting that the imputed data were representative of the original data (see Table 4.7).

4.5.3 Factors Associated With Completing CR

Thirty-five factors were coded as independent variables in a binary logistic regression related to not completing/ completing CR as a dependent variable using backward elimination and 32,336 cases (see Table 4.8). The final model was statistically significant, $\chi^2 (37) = 699.608$, correctly classifying 80.8% of cases. Hosmer and Lemeshow test value $\chi^2 (8) = 10.452$ and p-value = 0.235, which means it was nonsignificant.

The ROC curve test indicates that the model has an acceptable predictive ability with an AUC of 0 0.603 (SE = 0.004, 95% CI: 0.595, 0.611) (see Figure 4.2). In addition, the assumptions of the logistic regression model were assessed and found to be not violated. The measures of classification performance were computed at the default cut-off point of 0.50, which resulted in a high sensitivity but low specificity, and since the relationship between both values represents a trade-off, a new cut-off point (0.810) was chosen to maximise both values (see Table 4.9).

Table 4.8 The Binary Logistic Regression 6 Blocks

The Regression Blocks	Factors	−2 Log likelihood	Nagelkerke R²	Overall Model accuracy
Block 1	**Treatment type**	31,677.587	<0.001	80.7%
	waiting time			
Block 2	**Age (mean-centred)**	31,306.894	0.019	80.7%
	Gender			
	Age* Gender			
	Ethnicity			
	Partnership status			
	SES			
Block 3	**Hospital length of stay**	31,115.246	0.029	80.7%
	Previous CR			
	Angina			
	Diabetes mellitus			
	Hypertension			
	Anxiety			
	Depression			
	Family history of CVD			
	Hyperlipidaemia			
	Number of comorbidities			
	Previous CABG			
	A diagnosis of ≥ 2 cardiac events			
	Previous cardiac events			
Block 4	**Confirmed joining date**	31,017.858	0.033	80.7%
	Smoking			
	BMI			
	Physical activity (150 min/week)			
	Employment			
	HADS-Anxiety			
	HADS-Depression			
	Social support			
	Alcohol consumption			
Block 5	**CR delivery mode**	30,999.513	0.034	80.8%
	Referring health professional			
	Referral Source			
Block 6	**Multidisciplinary team**	30,999.513	0.034	80.8%
	BACPR certified programme			

SES: socioeconomic status. CVD: cardiovascular disease. AMI: Acute myocardial infarction. CABG: coronary artery bypass grafting. CR: cardiac rehabilitation. CVD: cardiovascular disease. BMI: body mass index. HADS: Hospital Anxiety and Depression Scale. BACPR: British Association for Cardiovascular Prevention and Rehabilitation.
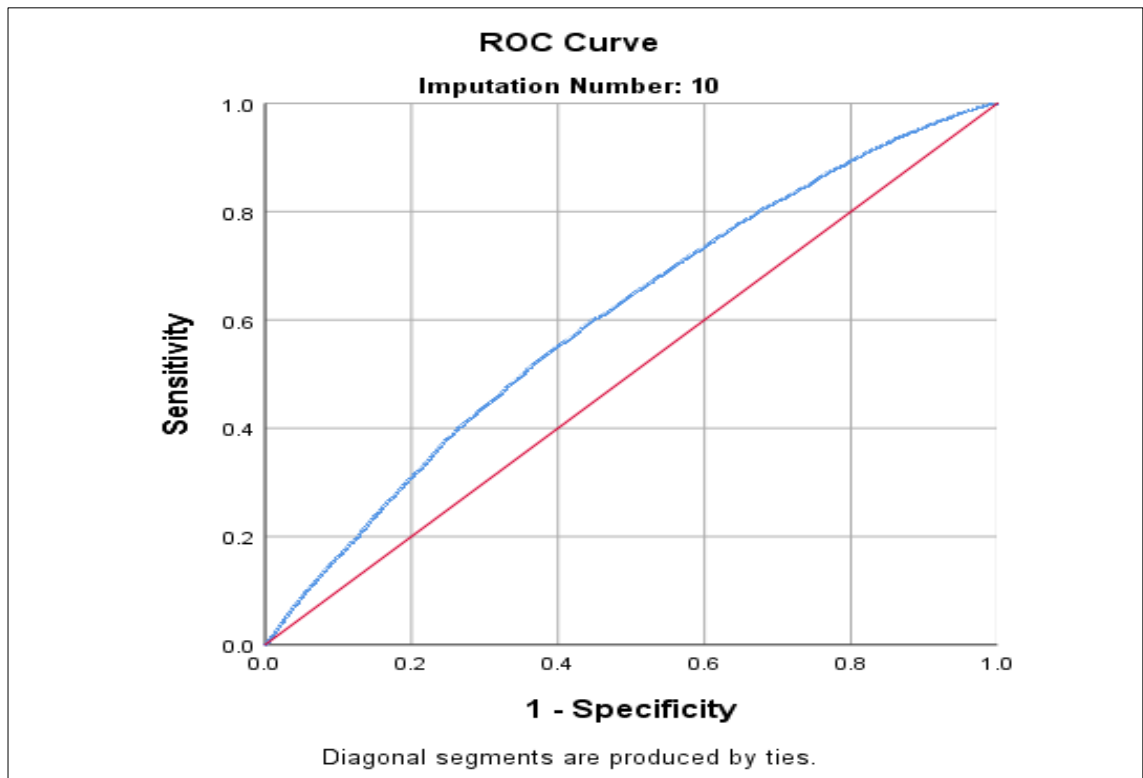
Figure 4.2 ROC Curve for Final Completing CR Model

ROC: receiver-operating characteristic

Table 4.9 The Measures of Classification Performance at Different Cut-Off Points

classification performance	cut-off point (0.500)	a new cut-off point (0.810)
Sensitivity	99.97%	59.95%
Specificity	0.18%	55.36%

4.5.3.1 Significant Factors Associated With Completing CR

Thirty-five independent variables were included in the logistic regression analysis, and 21 were significantly associated with CR completion (see Table 4.10, 4.11) and (see Figure 4.3). For unadjusted OR from the logistic regression, see Appendix K.

Table 4.10 Three Measures of Waiting Time from 3 Different Models of Logistic Regression

Factors (reference)		OR	95% C. I		p-value*
			Lower	Upper	
Waiting time (≤ 6 weeks WT)	> 6 weeks WT	0.94 (6%)	0.89	0.99	< 0.05
Waiting time	In weeks	0.99 (0.5%)	0.99	0.99	< 0.05
Waiting time (WT ≤ 2 weeks)	2 > WT ≤ 4 weeks	1.05	0.93	1.17	0.422
	4 > WT ≤ 6 weeks	1.09	0.98	1.20	0.122
	6 > WT ≤ 8 weeks	0.94	0.84	1.05	0.303
	WT > 8 weeks	1.01	0.93	1.10	0.805

*Significant if p-value < 0.05.

WT: waiting time. OR: odds ratio. CI: confident intervals.

Table 4.11 Logistic Regression Results for Completing Cardiac Rehabilitation

Factors (references)		OR	1/ OR	95% CI Lower	95% CI Upper	p-value*
Waiting time (≤ 6 weeks WT)	> 6 weeks WT	0.94	1.06	0.89	0.99	0.049
Treatment type (CABG)	Valve Surgeries	0.87	1.15	0.81	0.93	<0.001
	CABG/valve	0.88	1.14	0.80	0.97	0.009
Age (mean-centred)	In years	1.02	-	1.02	1.03	<0.001
Gender (Male)	Female	0.92	1.09	0.86	0.98	0.015
Gender* Age	-	0.99	-	0.99	1.00	<0.001
Partnership status (Not partnered)	Partnered	1.18	-	1.10	1.26	<0.001
SES (First quintile most deprived)	Second quintile	1.25	-	1.13	1.38	<0.001
	Third quintile	1.32	-	1.20	1.46	<0.001
	Fourth quintile	1.46	-	1.33	1.61	<0.001
	Fifth quintile	1.53	-	1.40	1.68	<0.001
Angina (No)	Yes	1.10	-	1.02	1.18	0.009
Diabetes mellitus (No)	Yes	0.85	1.17	0.80	0.92	<0.001
Depression (No)	Yes	0.75	1.33	0.66	0.85	<0.001
Hyperlipidaemia (No)	Yes	1.14	-	1.06	1.22	<0.001
Number of comorbidities (No comorbidity)	1-2 comorbidities	0.89	-	0.76	1.04	0.146
	≥ 3 comorbidities	0.78	1.28	0.66	0.93	0.005
Previous cardiac events (No previous events)	Previous events	0.86	1.16	0.81	0.92	<0.001
A diagnosis of ≥ 2 cardiac events (CABG and\or Valve)	CABG and\or Valve plus AMI	0.97	-	0.89	1.06	0.496
	CABG and\or Valve plus PCI	0.63	1.59	0.42	0.93	0.021
	CABG and\or Valve plus AMI + PCI	0.81	-	0.62	1.06	0.128
Hospital length of stay (≤ 6 days)	7-9 days	1	-	0.92	1.08	0.936
	10-16 days	0.92	1.09	0.85	0.99	0.030
	≥ 17 days	0.94	-	0.87	1.02	0.140
Confirmed joining date (No)	Yes	1.21	-	1.14	1.30	<0.001
HADS-Depression (Normal)	Borderline/clinically depressed	0.83	1.20	0.78	0.89	<0.001
BMI (< 30 kg/m²)	≥ 30 kg/m²	0.91	1.10	0.85	0.97	0.002
Physical activity (150 min/week) (No)	Yes	1.12	-	1.06	1.19	<0.001
Smoking (No)	Yes	0.66	1.51	0.57	0.77	<0.001
CR delivery mode (Supervised delivery)	Self-delivered	0.91	1.10	0.84	0.98	0.009
Referring health professional (Consultant/cardiac nurse)	GP/primary care nurse	1.03	-	0.86	1.25	0.733
	Other	1.16	-	1.06	1.28	0.002

* Significant if p-value < 0.05.
Note: Not significant Variables (ethnicity, partnership status, hospital length of stay, previous CR, hypertension, anxiety, family history of CVD, previous CABG, employment, HADS-Anxiety, social support ,alcohol consumption, referral source, multidisciplinary team , BACPR certified programme). %: percentage. AMI: acute myocardial infarction. BMI: body mass index. HADS: Hospital Anxiety and Depression Scale. CABG: coronary artery bypass grafting. CR: cardiac rehabilitation. CVD: cardiovascular disease. PCI: percutaneous coronary intervention. WT: waiting time. OR: odds ratio. CI: confident intervals. SES: socioeconomic status. GP: general practitioner.

Significant Independent Factors	Odds Ratio [95% CL]
A diagnosis of two or more events	0.63 [0.42, 0.93]
Smoker (Yes)	0.66 [0.57, 0.77]
Depression Yes	0.75 [0.66, 0.85]
Number of comorbidities (3 ≥ comorbidities)	0.78 [0.66, 0.93]
HADS-depression (Borderline/clinically depressed)	0.83 [0.78, 0.89]
Diabetes (Yes)	0.86 [0.80, 0.92]
Previous events (Yes)	0.86 [0.81, 0.92]
Treatment type (Valve Surgeries)	0.87 [0.81, 0.93]
Treatment type (CABGPlusValve)	0.88 [0.80, 0.97]
BMI (≥ 30 kg/m2)	0.91 [0.85, 0.97]
CR delivery mode (Self-delivered)	0.91 [0.84, 0.98]
Hospital length of stay (10-17 days)	0.92 [0.85, 0.99]
Gender (Female)	0.92 [0.86, 0.98]
Waiting time (> 6 weeks)	0.94 [0.89, 0.99]
Age (Years)	1.02 [1.02, 1.03]
Angina (Yes)	1.10 [1.02, 1.18]
Regular physical activityn (Yes)	1.12 [1.06, 1.19]
Hyperlipidaemia Yes	1.14 [1.06, 1.22]
Referring health professional (Other)	1.16 [1.06, 1.28]
Partnership status (Partnered)	1.18 [1.10, 1.26]
Confirmed joining date (Yes)	1.21 [1.14, 1.30]
SES (2nd Quintile)	1.25 [1.13, 1.38]
SES (3rd Quintile)	1.32 [1.20, 1.46]
SES (4th Quintile)	1.47 [1.33, 1.61]
SES (5th Quintile)	1.53 [1.40, 1.68]

Not Completing CR   Completing CR

Figure 4.3 Forest Plot of Significant Independent Factors From Regression Analysis for Completing CR.

HADS: Hospital Anxiety and Depression Scale. CABG: coronary artery bypass grafting. BMI: body mass index. CR: cardiac rehabilitation. SES: socioeconomic status.

4.5.3.1.1 Waiting Time

The waiting time association with CR completion was investigated using the 3 measurements in 3 separate models (see Table 4.10). In the first model, the primary waiting time measurement, there was a significant association between waiting time and CR completion, with patients with > 6 weeks WT less likely to complete CR compared to patients with ≤ 6 weeks WT (OR: 0.94, 95% CI: 0.89, 0.99). In the second model, waiting time in weeks as a continuous variable was also statistically significant as the likelihood of completing CR decreased by 0.5% for every increase of waiting time by a week. Finally, the last waiting time measurement with 5 categories was not significant.
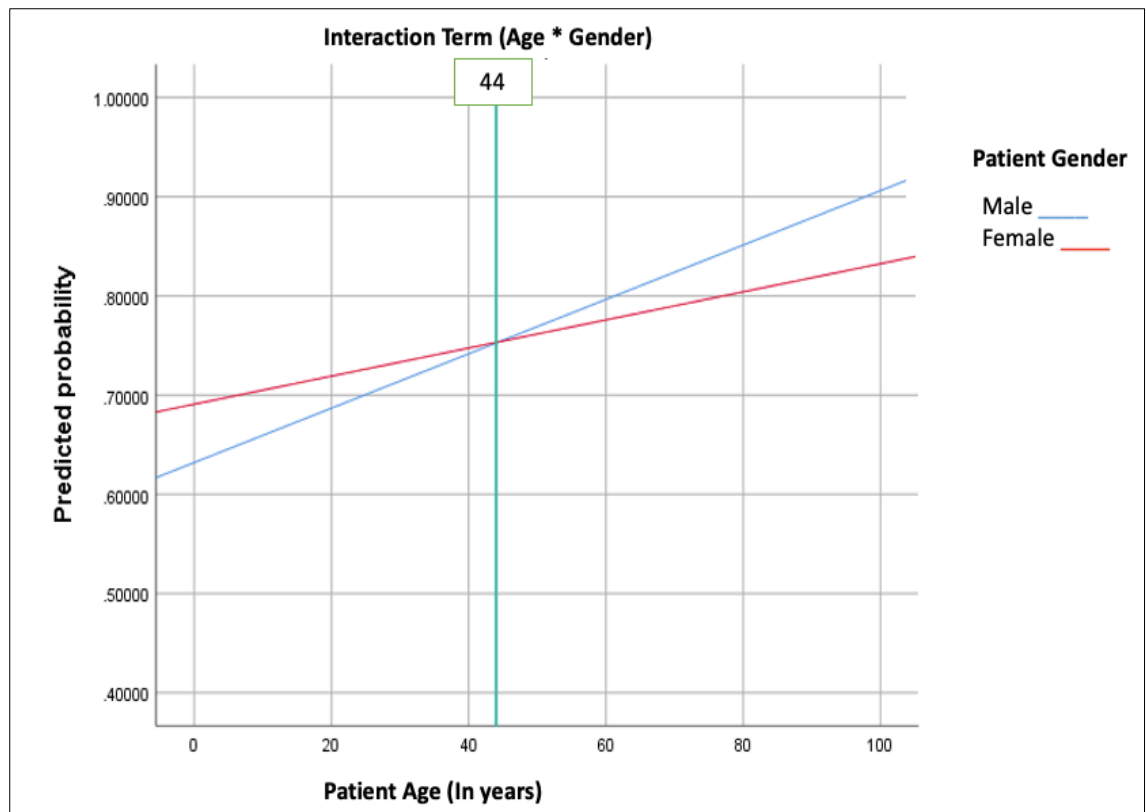
Figure 4.4 Interaction Relationship (Age*Gender) When Completing CR
CR: cardiac rehabilitation.

4.5.3.1.2 Patient Factors

Patient age (centred to mean age) was associated with completing CR, in that for each year the population became older, their probability of CR completion increased by 2.4%.

Female patients were less likely to complete CR than male patients by an odds ratio of 0.92 (95% CI: 0.86, 0.98). The interaction term between age and gender was significant. Figure 4.4 shows that starting from the age of 18 years, female patients were more likely to complete CR than male patients until the age of 44 years, when the trend would shift to older female patients being less likely to complete CR compared to older male patients. Examining the partnership status of patients would show that being partnered increased the likelihood of completing CR by odds of 1.18 (95% CI: 1.10, 1.26) compared to not partnered. All the subcategories of social deprivation measured by SES were significant as the likelihood of completing CR increased when patients belong to higher quintiles compared to the lowest quintile, i.e., the odds of CR completion keep improving from the second quintile (OR: 1.25) until the fifth quintile (least- deprived area) with OR: 1.53. Both factors of patient ethnicity and history of previous CR were not significant.

4.5.3.1.3 Cardiac-Event Factors

The analysis showed a significant association between CR completion and the treatment type. Patients who underwent CABG had a higher probability of completing CR than post-valve surgeries or combined surgeries by an odds ratio of 1.155 and 1.38, respectively. Having a comorbidity of diabetes mellitus was associated with a decreased chance of completing CR by 15.0%, and having a history of depression reduced the odds of completion by 25.0%. On the other hand, patients with angina or hyperlipidaemia were more likely to complete CR by 10.0% times and 14.0% times, correspondingly. There was no association between hypertension, anxiety, or a family history of CVD with CR completion. While having 1-2 comorbidities was not associated with completing CR, having ≥ 3 comorbidities had an association where there was decreased chances of CR completion by OR: 0.78 (95% CI: 0.66, 0.93).

Furthermore, patients with previous cardiac events had less likelihood of completing CR by 0.86 times (95% CI: 0.81, 0.92) than patients with no previous cardiac events. As the

variable of a diagnosis of ≥ 2 cardiac events was tested, it showed that none of the subcategories was significant except for CABG and\or valve plus PCI, as it was associated with a lower chance of completing CR by 37.0%. Similarly, none of the hospital lengths of stay subcategories was significant, except for 9 to 15 days hospital length of stay, where it had a negative relationship with CR completion by OR: 0.92 (95% CI: 0.85, 0.99). Patients with a confirmed joining date had an increased likelihood of CR completion by 1.21 times (95% CI: 1.13, 1.30).

4.5.3.1.4 Pre-CR Assessment Factors

Out of the 8 pre-CR assessment factors, 4 factors were significant (HADS-Depression, BMI, physical activity (150 min/week), smoking), whereas the others were not significant (HADS-Anxiety, social support, employment, and alcohol consumption). Patients who were assessed to be borderline or clinically depressed, based on the HADS, were less likely to complete CR by OR: 0.83 (95% CI: 0.78, 0.89). Another factor was patients' BMI; with a BMI of less than 30 kg/m^2, patients were more likely to complete CR by 10.0%. The analysis showed that practising regular physical activity (150 min/week) was associated with a better probability of completing CR by 1.12 (95% CI: 1.06, 1.19)., in contrast to being a smoker, which would lower the probability by 0.66 (95% CI: 0.57, 0.77).

4.5.3.1.5 CR Delivery Factors

CR delivery mode was statistically significant, where CR supervised delivery increased the likelihood of completing CR by 10.0% compared to self-delivery CR. Also, the likelihood of completing CR increased when "other" health care professionals issued patients the CR referral compared to a consultant/cardiac nurse by 1.16 (95% CI: 1.06, 1.28). On the other hand, the referral source, multidisciplinary team and receiving

rehabilitation from a BACPR certified programme were not statistically associated with CR completion.

4.6 Discussion

This study evaluated the level of association between completing CR and waiting time in addition to other factors. Among the 35 factors tested, waiting time and 21 factors were significantly associated with CR completion. Thus, the researcher rejected the null hypothesis and accepted the experimental hypothesis that states, "waiting time has an association with completing CR". Among the 68,580 patients who started CR, 79.0% (54,467 patients) were CR completers, while the remaining 21.0% (14,113 patients) failed to complete CR. When the percentage of CR non-completers in this study is compared to other research (Turk-Adawi and Grace, 2015), it indicates that many more patients complete CR in the UK, which is possibly attributed to improving levels of CR services in the UK (NACR, 2018).

4.6.1 Waiting Time

Since several national and international guidelines recommend that patients post cardiac surgeries delay the start of CR for 6 weeks (ACPICR, 2015; Piepoli et al., 2010; Royal Dutch Society for Physical Therapy, 2011), it was decided to create a waiting time variable to reflect starting CR early, i.e., $\leq$ 6 weeks WT or delay starting CR, i.e., > 6 weeks WT. In addition, the influence of waiting time was analysed in two other forms: when it increases by a 2-week interval or continuously by the unit of a week. Examining the distribution of CR completers showed there were more patients (55.0%) who started CR early with a waiting time of $\leq$ 6 weeks compared to patients (45.0%) who delayed starting CR with a waiting time of > 6 weeks, and the same observation applies for CR non-completers. Regression analysis revealed no statistically significant association between waiting time in the form of increased 2 weeks intervals and CR completion.

However, it showed the waiting time association to be statistically significant for CR completion between ≤ 6 weeks and > 6 weeks. As patients waited > 6 weeks to start CR, their probability of completing CR decreased by 6% compared to waiting within 6 weeks and starting CR earlier. Also, for every increase in waiting time of a week, the patient's chances of completing CR reduced by 0.5%. The objective of analysing waiting time was to investigate its part in facilitating or hindering CR completion and, subsequently, its association with CR outcomes and beneficial effects, with which the analysis indicated a negative association. In agreement with these findings were the results reported by Marzolini et al. (2015) when they analysed the data of 6,497 patients post-CABG and found that for every increase in waiting time by a day, from pre-CR assessment/or referral and the starting CR, there was an increase in the likelihood of CR non-completion by 2.215 times (95% CI: 1.664, 2.949) (Marzolini et al., 2015). Moreover, the prolonged waiting time was inversely associated with lower CR outcomes, namely the cardiopulmonary measurements of resting heart rate with an odds ratio: 0.047 (95% CI: 0.892, 3.472) and peak oxygen uptake with an odds ratio: −0.114 (95% CI: −2.104, −1.215). When examining patients' preferred selection of CR programmes, Boyde et al. (2018) recruited 200 participants to answer a discrete choice experiment survey where the results showed that 46.8% of the participants favoured CR programmes with a short waiting time and a start within 2 weeks from being discharged from the hospital, with 13.2% of the participants opted to for CR programme with 6 weeks waiting time (Boyde et al., 2018). It may be more effective if CR providers capitalise on patients' preference for a short waiting time and the data that support its positive impact by delivering a more tailored programme that would yield optimised outcomes.

4.6.2 Patient Factors

There was a direct association between age and completing CR, as the likelihood of CR completion increased by 2.4% for every increase in patient age by a year. Using a study

based on New Zealand CR audit data, these researchers investigated CR utilisation, including completion with 2,001 patients. They found that younger patients (less than 65 years) and older patients (more than 75 years) were less likely to complete CR by an odds ratio of 0.60 (95% CI: 0.41, 0.87) and odds ratio of 0.55 (95% CI: 0.33, 0.92), correspondingly (Doolan-Noble et al., 2004). In another study, 189 patients were recruited to undergo a 6 weeks CR programme to research factors associated with CR non-completion, and it reported that as patients get older, they were less likely to not complete CR by 0.89 times (95% CI: 0.82, 0.95) (Yohannes et al., 2007). However, it is recommended to be cautionary when interpreting this study's findings due to the small study size. Put another way; younger patients had a higher likelihood of not completing CR, which could be attributed to employment-related pressures, a need to return to work, or patients' inadequate education about CR benefits. Similarly, in a cohort study with 1,115 patients, Sarrafzadegan et al. (2007) reported that with the increase in age, there were increased the chances of completing CR by 1.5% (Sarrafzadegan et al., 2007). In 2016, a cohort study with 326 patients examined the relationship between different ageing groups and non-completing CR and stated that using the age group younger than 65 years as a reference, the age group 75 years and older was not significant, while patients aged between 65-74 years had a higher probability of not completing CR by 1.96 times (95% CI: 1.16, 3.29) (Nesello et al., 2016).

Comparing the presentation of males and females who completed CR, this study found that the completers were predominately male patients, with 76.8% versus 23.2% of female patients. Moreover, this study found that patients' gender does affect the likelihood of completing CR, as female patients were less likely to continue with the CR programme compared to male patients by an odds ratio 0.918 (95% CI: 0.858, 0.983). Similar findings in the research by Yohannes et al. (2007) showed that the majority of CR completers were male patients by forming 74.0% of the sample and whereas the female patients had a

higher possibility of not completing CR by 5.59 times (95% CI: 1.78, 17.4) compared to male patients (Yohannes et al., 2007). Likewise, the findings of Caulin-Glaser et al. (2007) research showed that women patients were 2.52 times more likely to drop out of the CR than male patients (Caulin-Glaser et al., 2007). Several reasons may deter women from completing CR, such as orthopaedic conditions, transportation difficulty, comorbidities, and being uncomfortable in mix-sex classes (Caulin-Glaser et al., 2007; Yohannes et al., 2007; Marzolini, Brooks and Oh, 2008; Andraos et al., 2015). Sarrafzadegan et al. (2007) reported contrary findings., as women had better chances of completing CR by 1.817 times; however, this may be specific to the Iranian population, where women had fewer social obligations to have a professional career which may mean having more time to attend and complete rehabilitation programme (Sarrafzadegan et al., 2007). Therefore, a comparison between this study and broader research should be limited due to possible differences in patient groups.

Another investigation examined whether being female or the interactions of age and gender would be significant with not completing CR (Casey et al., 2008). The research involved analysing the results of 600 cardiac patients who participated in a CR programme and found that gender was not associated with CR completion. Furthermore, there was a nonsignificant association between the interactions regarding age and gender and completing CR, which was the opposite of this study's results. Significant interactions yielded between age and gender, as for the age between 18 to 44 years old, females would have a better likelihood of completing CR compared to their counterparts in male patients. From 44 years and older, the trend towards completion would shift in favour of male patients as they would have a higher probability of completing CR than female patients in the same age group. In an observational study with 1,089 (18.4%) female patients and 4,833 (81.6%) male patients, it was reported that below the age of 55 years, both males and females had a greater probability of not completing CR (Marzolini,

Brooks and Oh, 2008). Younger women may be less constrained by musculoskeletal conditions or comorbidities and recognise the importance of staying healthier by completing CR, while younger men have more need to go back to work, are challenged by time conflicts or are less aware of CR necessity.

In terms of personal relationships, being partnered was significantly associated with completing CR by 1.176 times. Some studies support these results, such as stated by Marzolini et al. (2008) that not being married increase the odds of not completing CR by an odds ratio 1.385 (95% CI: 1.200, 1.559) (Marzolini, Brooks and Oh, 2008) and Laustsen et al. (2013) reported that not partnered had the odds ratio of 1.12 (95% CI: 1.07, 1.70) to fail to complete CR (Laustsen, Hjortdal and Petersen, 2013). For some patients, having a partner means attaining much-needed social and financial support, which would help the patient complete the CR programme.

The IMD scale was used to study the influence of SES on the patients and utilising CR services; it starts from the most deprived status, defined as the first (lowest) quintile of SES, up until the fifth quintile, which is described as the least deprived area. The 5 socioeconomic categories were equally presented for CR non-completers, with two thousand patients in each category. For CR completers, the distribution differs as fewer patients from the lowest quintile (12.2%), and as the SES increase, more patients would complete CR, to end up with the highest percentage of 27.8% for the fifth quintile. Similarly, there was a positive association between SES and completing CR with the second to fifth SES compared to the lowest quintile; there was progressive improvement in the probability of CR completion; the second quintile: 25.0%, third quintile: 32.0%, fourth quintile: 46.0%, fifth quintile 53.0%. The disparities in patients' SES were reflected in their likelihood of completing CR; for example, comparing patients from two different neighbourhoods' income levels, the data showed a higher chance for patients from low-income neighbourhoods not completing CR by OR: 1.38 compared to patients

from the high-income neighbourhood (Lemstra et al., 2013). In an analysis done by Doolan-noble et al. (2004) through exploring New Zealand CR audit data and the country version of the index of multiple deprivation scale, the data showed that patients from the middle, more deprived areas had a reduced likelihood of completing CR compared to the least deprived areas (Doolan-Noble et al., 2004). The influence of SES on completing CR extended from influence within the same population to influence on different populations from different countries and its classification based on their income. Turk-Adawi and Grace (2015) used a meta-analysis of 11 studies from countries with high and middle income (no low incomes publications were found), concluding that the rate of CR non-completion was more for middle-income countries as it reached 82.0% compared to high-income countries as it reached 56.0% (Turk-Adawi and Grace, 2015). Low SES, with its links to health illiteracy (Stormacq, Van Den Broucke and Wosinski, 2019) and inadequate logistic support, maybe in action with influencing CR completion.

Both the history of previous CR and patients' ethnicity were not significantly associated with completing CR. While Zang et al.(2017) did not find a significant association between CR completion and ethnicity in a racially mixed sample (Zhang et al., 2017), other studies found an association where patients of white ethnicity were more likely to complete CR or ethnic minorities less likely to complete CR (Prince et al., 2014; Pollmann, Frederiksen and Prescott, 2017).

4.6.3 Cardiac-Event Factors

This study evaluated the association between CR completion and the 3 treatment types of CABG, valve surgeries, or combined surgeries. The most common cardiac surgery was CABG by 57.8% for CR completers (55.2% non-completers), then valve surgeries by 31.4% for CR completers (34.1% non-completers), where CABG/valve surgeries were the least common by making 10.8% of CR completers (10.7% non-completers). The regression analysis resulted in a significant relationship as the probability of completing

CR was reduced when the treatment types were valve surgeries or CABG/valve surgeries compared to CABG by OR: 0.87 (95% CI: 0.81, 0.93) and OR: 0.879 (95% CI: 0.80, 0.97), respectively. Ratchford et al. (2004) found that among 424 cardiac patients (post-AMI, PCI, CABG), 319 patients completed CR, while the remaining 105 failed to complete the rehabilitation programme. Also, they found that patients post-CABG were more likely to complete CR than patients post-AMI odds ratio: 2.0 (95% CI: 1.01, 4.27) (Ratchford et al., 2004). The populations of 3 studies that included patients with post-surgical and non-surgical diagnoses had reported findings consistent with this study's results. The study by Marzolinia et al. (2008) reported that patients not post-CABG were more likely not to complete CR (Marzolini, Brooks and Oh, 2008); likewise, the findings by Nesello et al. (2016), where the odds ratio was 2.76 for not completing CR (Nesello et al., 2016); additionally, patients post-CABG were more likely to complete more than half the sessions in the CR programme (Turk-Adawi et al., 2013). Although the majority of literature supports an existing relationship between treatment type and CR completion, some contradictory reports failed to find any associations (Caulin-Glaser et al., 2007; Laustsen, Hjortdal and Petersen, 2013). The higher probability of patients post-CABG completing CR could mirror the consciousness regarding the seriousness of the surgery and the need for a rehabilitation programme, or it could correspond to the higher number of patients post-CABG compared to other treatment types.

There was a variation of associations between the CVD comorbidities and CR completion. While hypertension, anxiety and a family history of CVD were not statistically significant, diabetes mellitus, depression, angina, and the number of comorbidities were significant. Diabetes mellitus has an inverse relationship with completing CR, as being diabetic would decrease the probability of CR completion by 0.86 (95% CI: 0.80, 0.92). Other studies reported a similar trend as Worcester et al. (2004), where they reported an odds ratio: 3.38 of for not completing CR. Marzolini,

Brooks and Oh (2008) reported an odds ratio: 1.21 for failing to complete CR, Wittmer et al. (2012) found an odds ratio: 1.48 for CR non-completers and Forhan et al. (2013) showed an increase in CR non-completion for diabetic with odds ratio: 1.22. Dissimilar results were found in other studies, such as Sanderson et al. (2003) where they found being diabetic lowered the chance of not completing CR by an odds ratio: 0.5, while Turk-Adawi et al. (2013) reported an odds ratio: 1.30 for diabetic patients to complete 21 or more CR sessions. Research that found a negative association between patients with diabetes mellitus and completing CR attributed it to these patients, that due to the nature of the disease, had already established their health regime, so they did not see a necessity for a CR programme or they could complain from additional comorbidities that may deter them.

Hyperlipidaemia was associated with increasing the chance of completing the CR by 14.0%, contrary to other studies that found no link to completing more than 21 CR sessions or the programme as a whole (Turk-Adawi et al., 2013; Ratchford et al., 2004). Limited studies measured the association between hyperlipidaemia and CR completion and had inconsistent findings regarding hyperlipidaemia and lipid profile. Some studies found that patients who attend higher CR sessions had hyperlipidaemia (Sarrafzadegan et al., 2007; Dorn et al., 2001), a study that found lipid profiles worse among CR non-completers (Beckie et al., 2015). In addition, a study reported the lack of hyperlipidaemia management to be associated with failing to complete CR by 1.18 (Marzolini, Brooks and Oh, 2008); lastly, a study reported that CR completers had lower hyperlipidaemia incidents (Grace et al., 2016).

Chest pain in the form of angina was relatively uncommon among the population; 18.3% of CR completers and 17.4% of CR non-completers reported having angina. The data showed that having angina increases the likelihood of completing CR by 10.0%. Patients with angina may perceive their situation as more severe and would be more motivated to

complete the rehabilitation programme. Unlike angina, patients with ≥ 3 comorbidities had the probability of completing CR decreased by 22.0% compared to patients with no comorbidity, as it seemed that having ≥ 3 comorbidities could be very challenging and obstructive. Admittedly, just the presence of comorbidities was associated with decreasing the chances for CR completion for studies with surgical and non-surgical cardiac interventions (Pardaens et al., 2017; Resurrección et al., 2019). However, when it came to classifying comorbidities according to the total number, this research found only one study by Al Quait et al. (2018) where the factor was not significantly associated with completing CR for the post-PCI population.

As Ratchford et al. (2004) reported that having a diagnosis of ≥ 2 cardiac events increased the chances of completing CR, this study found only a diagnosis of CABG and\or Valve plus PCI to be significant and with a decreased chance of completing CR by 37.0%. Being diagnosed previously with a cardiac event limits the patients' chances of completing CR by 14.0% compared to patients with no history of previous cardiac events. A prior study did not find a significant relationship between completing CR with a history of previous cardiac events, whether in a population of AMI, PCI, and CABG (Ratchford et al., 2004) or a population of PCI only (al Quait, 2018) nor with history of ACS in a population of ACS (Campbell et al., 2018).

For this study, the median hospital length of stay was 9 days, and the regression analysis showed no association between completing CR and any length of stay periods up to 9 days or ≥ 17 days. Only hospital length of stay between 10-16 days was significant with a negative association as it decreased the probability of completing CR by odds ratio: 0.92 (95% CI: 0.85, 0.99). By examining the literature, it seems that prolonged hospitalisation and CR completion are interlinked, meaning that prolonged length of stay would contribute to CR non-completion, and failing to complete CR would increase the risk of rehospitalisation (Martin et al., 2012). Furthermore, not only was the prolonged hospital

stay found to be linked to CR completion but it was also linked to longer waiting time and delay in starting CR, as reported by Johnson et al. (2014) when they investigated the relationship between cardiac risk factors and CR outcomes to waiting time.

Having a confirmed joining date for CR was found to have a significant positive association with starting CR by an odds ratio of 3.80 (95% CI: 3.58, 4.02), so its association with CR completion were also examined and was found to have a positive association by odds ratio 1.21 (95% CI: 1.14, 1.30). This could be due to patients with a confirmed joining date making up the majority of CR completers by 40,495 (74.3%), compared to CR non-completers by 13,972 (25.7%).

4.6.4 Pre-CR Assessment Factors

As several factors, such as HADS-Depression and BMI, were evaluated during the pre-CR assessment as baseline measures of CR outcomes, their contributions were studied to define the extent they were associated with CR completion. In addition, depression and anxiety were included in the analysis in 2 forms, firstly as being comorbidities and part of cardiac-event factors and, secondly, being baseline measurements and part of pre-CR assessment factors. The regression yielded similar results where depression (comorbidity) and HADS-Depression had negative associations with CR completion and anxiety (comorbidity), and HADS-Anxiety had a nonsignificant association with completing CR. Patients diagnosed with depression or their scores at HADS indicated borderline/clinical depression; they were less likely to complete CR by an odds ratio of 0.75 (95% CI: 0.66, 0.85) and 0.83 (95% CI: 0.78, 0.89), correspondingly. In line with this study's findings, a study with 1,902 medical and surgical cardiac patients reported it was twice more likely to not complete CR for patients borderline/clinically depressed compared to normal patients. At the same time, HADS-Anxiety was not significantly associated with CR completion (Turner et al., 2002). Yohannes et al. (2007) reported that based on the HADS scale, psychologically distressed patients were 1.48 more likely not to complete CR than

normal patients. Being graded with moderate or severe depression symptoms on the Beck Depression Inventory was described to increase the likelihood of not completing CR by 5.65 times (Caulin-Glaser et al., 2007). There is consensus in the literature that patients with manifested depression or anxiety symptoms had a lower probability of completing CR (Glazer et al., 2002; Casey et al., 2008; Pardaens et al., 2017; Rao et al., 2019). It seemed that mental disorders lead patients to have an amplified illness perception and to feel overwhelmed by their conditions, discouraging them from completing CR. Therefore, mental evaluation should continue as an essential part of the CR programme to help identify patients needing extensive psychological support during CR.

Most of the study population had a BMI of less than 30 kg/m^2 (i.e., not obese), representing 74.0% of the CR completers and 68.0% of CR non-completers. Being obese (BMI $\geq$ 30 kg/m^2) was significantly associated with decreasing the likelihood of completing CR by 0.91 times (95% CI: 0.85, 0.97). This study's results agreed with the results of several publications (Sanderson et al., 2003; Sanderson and Bittner, 2005; Sarrafzadegan et al., 2007; Wittmer et al., 2012). In a study with 12,003 cardiac patients to investigate the association between obesity (and diabetes mellitus), Forhan et al. (2013) stated that patients with obesity were 1.19 more likely not to complete CR, which could be because decreased exercise self-efficacy caused unhealthy behaviours, including dropping out of CR programmes. Most of the population had a sedentary lifestyle where they lacked regular physical activity (150 min/week), while the physically active patients form the minority of 38.6% of CR non-completers, which increased to 45.8% of CR completers. The likelihood of completing CR was associated with performing physical activity (150 min/week) by 12.0%, which concurs with other studies (Sanderson et al., 2003; Worcester et al., 2004). A small but important percentage of the patients were smokers, with 5.7% and 2.5% not completing and completing CR, respectively. Non-smokers had 51.0% better chances of completing CR compared to smokers. A systematic

review examined the relationship between smoking and CR utilisation; out of the 56 included studies, 21 studies informed about CR completion and out of that, there were 13 studies reported smoking to be significantly associated with failing to complete CR, while 6 studies found no association (Gaalema et al., 2015). It was suggested that smoking correlates with limited education, lower SES as well as lower physical fitness, which each alone or all combined would put patients at a disadvantage when it came to completing CR.

4.6.5 CR Delivery Factors

The associations between the five CR service-related factors and CR completion were investigated. It was found that CR delivery mode and referring health professional had significant associations. At the same time, the CR referral source, multidisciplinary team and BACPR certified programme had no associations. The distribution of patients between the two CR delivery modes showed a preference for the allocation of supervised CR delivery by 79.3% compared to self-delivered CR by 20.7% among the CR completers and a similar preference among CR non-completers (76.0% supervised CR delivery, 24.0% self-delivered CR). The analysis showed that patients assigned to supervised CR delivery were more likely to complete the CR programme by 10.0% compared to patients in the group of self-delivered CR. Supervised CR delivery is usually conducted inside a hospital and within a group, whereas self-delivered CR is usually at home and individually. There are many justifications for choosing one mode of delivery over the other. As for supervised CR delivery, patients believe that professional supervision would help them combat their lack of confidence and discipline, where being a member of a group would offer them a sense of support and where to spend efforts and time in travelling to the CR site would affirm the importance of the rehabilitation programme (Wingham et al., 2006). The self-delivered CR is seen as more accommodating to patients who do not want to travel to CR centres or have issues with travelling and is more suited

for patients whom preferer exercising alone (Wingham et al., 2006). Turk-Adawi et al. (2013) analysed the data of 4,412 cardiac patients where patients were allocated to individual or group CR sessions that included psychological support, nutrition education and more. They found that patients in treatment groups were more likely to complete more than half of the programme. There appear to be no differences between the effectiveness of the 2 modes of delivery; a Cochrane review of 23 randomised trials with 2,890 patients concluded that both models are equivalent in improving cardiac outcomes (Anderson et al., 2017). However, since the CR delivery mode would influence a patient's chances of completing CR, which in turn would influence CR outcomes, CR providers should factor this in when assigning patients to different delivery modes.

Referral to CR is the starting point of the service, with the eligible patients usually being referred to CR services by a healthcare professional such as a cardiac consultant, cardiac nurse, or GP/primary care nurse. During the NACR routine data entry for the variable "referring health professional", if the referral came from none of those professionals, it would be coded as other. Examining the distribution of patients for "referring health professional" showed that the majorities of referrals were by a consultant/cardiac nurse (CR completers: 85.4%, CR non-completers: 88.0%) then "other" (CR completers: 12.3%, CR non-completers: 10.1%) and minorities were from GP/primary care nurse (CR completers: 2.3%, CR non-completers: 1.9%). Comparing GP/primary care nurse and "other" to a consultant/cardiac nurse, logistic regression yielded only significant association for the "other" category as patients referred by "other" were more likely to complete CR by 16.0%. Although most referrals came from a consultant/cardiac nurse, it was insufficient to influence patients to complete CR, and it was overpowered by referrals from "other". It may be advisable to investigate the category "other" more, identify them, and employ their weight and role in completing CR.

4.7 Strengths and Limitations

One of the key strengths of this study lay in its generalisability due to the large sample number and being representative of routine clinical practice. Most studies investigating association through regression analysis suffer from small sample sizes (Glazer et al., 2002; Yohannes et al., 2007). As most observational studies use routine data, the extent of missing data remains a major issue and was in part accounted for by using multiple imputations to reduce the selection bias and avoid the reduction in population representation as well as statistical power that may occur if complete case analysis was used. Another issue that the inability to adjust the analysis for all factors because they may be unknown or known (such as cardioprotective medication use or travel time to the CR centre) but unavailable in the database.

4.8 Conclusion

This study has shown that waiting time was inversely associated with the likelihood of completing CR in a population of post-median sternotomy. The factors associated with increased chances of CR completion were being a patient with a post-CABG as treatment type, being older, being a woman under 44 years or a man older than 44 years, being partnered, having a higher SES, having the comorbidities of angina or hyperlipidaemia, having confirmed joining date, being physically active, being referred to CR by other. Also, there were the factors that were associated with decreased probability of completing CR, and there were: being female, having the comorbidities of diabetes mellitus or depression, having ≥ 3 comorbidities, having previous cardiac events, a diagnosis of CABG and\or Valve plus PCI, a 10 – 16 days hospitalisation, being borderline/clinically depressed, having BMI ≥ 30 kg/m^2, being smoker, having self-delivered CR. Therefore, the need for patients with a reduced likelihood to complete CR should be anticipated when designing CR programmes to halt dropping out and ensure they reap the benefits of CR.

CHAPTER 5 Waiting Time and CR Outcomes for Post-Surgical Cardiac Rehabilitation Patients

5.1 Background

This thesis's chapters 3-4 focused on exploring the association between waiting time and utilising CR services through 1) starting and 2) completing the rehabilitation. While the previous 2 chapters concluded that there was an association between waiting time and starting and completing CR, it is unknown if there is a difference in CR outcomes specifically for patients post sternotomy. This study will be the first to evaluate this research question using routine practice data on CR outcomes for all major core components of the BACPR. According to the BACPR, cardiovascular risk factors, psychological health, and physical fitness are part of CR's core components (BACPR, 2017). Through a tailored CR programme, there is an expected reduction of cardiovascular risk factors and optimisation for psychological and physical health (Cowie et al., 2019). This is accomplished through assessments and monitoring of comprehensive CR using various types of group sessions or consultations (e.g., nutrition, pharmacy, psychology), structured exercise training, and education session carried out by a multifaceted professional team (BACPR, 2017).

Waiting time and how long patients should wait to commence CR continues to be a focus of national discussions, with national guidelines recommending waiting 6 weeks post-sternotomy as a measure of surgical wound protection (NICE, 2013). However, on the other hand, some researchers challenged the validity of this practice and have shown to cause adverse effects (Fell, Dale and Doherty, 2016). Therefore, in this thesis literature review, there was an effort to find research that compared the effect of short waiting time vs long waiting time to start CR on CR outcomes; and to date, there were only 3 cohort

studies and a randomised control trial (Pack et al., 2015; Marzolini et al., 2015; Fell, Dale and Doherty, 2016; Ennis et al., 2022).

This study will explore the influence of waiting time using a broader scope of CR outcomes, more recent records, and a higher volume of data that would reflect the UK population's demographics and ensure more robust analyses. This study aimed to determine if waiting time is associated with CR outcomes grouped as cardiovascular risk factors, psychological health, and physical fitness for patients following CABG post-valve surgeries and combined CABG and valve surgeries using the NACR data.

5.2 Study Objective

This observational study used national audit data for patients following CABG, cardiac valve surgery and patients who had both types of surgeries, intending to design, conduct, analyse and interpret the findings to determine the level of association between waiting time and routinely reported patient outcomes.

- Cardiovascular risk factors: obesity, smoking, physical activity (150 min/week) and blood pressure.

- Psychological health: HADS-Depression, HADS-Anxiety, feelings (Dartmouth), QOL (Dartmouth).

- Physical fitness: 6MWT, incremental shuttle walk test (ISWT) and physical fitness (Dartmouth).

This chapter will address the overall question, "What factors are associated with waiting time and cardiac rehabilitation outcomes?".

The study nondirectional (a two-tail test) hypotheses were formed for each of the 11 outcomes, with each dependent having a null hypothesis and an experimental hypothesis; below are examples:

- H0 (null): Waiting time factor has no association with the cardiovascular risk factor outcome of obesity.

- H1 (experimental): Waiting time factor has an association with the cardiovascular risk factor outcome of obesity.

- H0 (null): Waiting time factor has no association with the cardiovascular risk factor outcome of smoking.

- H1 (experimental): Waiting time factor has an association with the cardiovascular risk factor outcome of smoking.

The complete list of tested hypotheses is listed in Appendix L.

5.3 Methods

5.3.1 Study Design

The study was a retrospective observational study that included adult male and female patients aged 18 years and older who underwent CABG heart valve surgeries combined through a median sternotomy without exclusion criteria. The data source used was the NACR database from 1/1/2013 to 31/12/2019. Due to the disruption that faced the NHS services as a result of the Covid-19 coronavirus pandemic, none of the data from 2020 was used (Mafham et al., 2020; British Heart Foundation, 2020). The checklist of the STROBE Statement was used when reporting for this study (Von Elm et al., 2014) (Appendix M).

5.3.2 Data Sources

This study included adult patients post-cardiac surgeries in the NACR database. Since the study involved investigating the association of waiting time with cardiac rehabilitation outcomes, it was necessary only to include patients with valid waiting times, i.e., removing cases with negative waiting times as results of data entry errors or waiting time that was more than a year, these long times were an indication of unknown issues. In

addition, all cases included had completed CR with both the pre and post-CR measurements for the outcomes. The outcomes investigated in this study were for the cardiovascular risk factors, psychological health, and physical fitness, considering they are core components of CR. Based on the reduced sample size, due to valid case analysis of outcomes, some independent variables used in previous chapters were not utilised in this study: the history of CABG, previous cardiac events, and referral sources.

5.3.3 The Study Variables

This study used regression analyses and the explanatory variables of waiting time (the binary variable), the baseline of CR assessment, i.e., outcomes from pre-CR assessment, and patient factors, cardiac-event factors, and CR delivery factors (see Table 3.1 and Table 4.1). Meanwhile, the dependent variables were outcomes collected after the completion of CR at post-CR assessments. The CR assessments' outcomes measure cardiovascular risk factors, psychological health, and physical fitness (see Table 5.1). While the values CR outcome measurements were recorded in scale and linear forms, in this study, except for the values of 6MWT and ISWT, they were dichotomised. The purposes of grouping the outcomes into binary variables were to clarify and align with the diagnostic cut-points (e.g., if a patient was hypertensive or not) and allow future comparisons with other research with similar dichotomisation. In the previous 2 chapters, the binary responses for the outcomes were coded to start with the unfavourable and then the favourable. E.g., completing CR responses were (No, Yes), the same method was used for this chapter's outcomes, e.g., smoking or not was classified into binary (Yes, No) or unhealthy and healthy responses to the QOL on the Dartmouth chart were classified into (No, Yes).

For cardiovascular risk factors, patient data were obtained from 4 risk factors, i.e., blood pressure, smoking, physical activity (150 min/week) status, and obesity. Monitoring patients' psychological health entailed evaluating their anxiety, depression, feelings

(Dartmouth) and QOL (Dartmouth). Moreover, they would be assessments for physical

fitness through the ISWT or 6MWT and patients' estimation of their physical fitness. Any

categorisation of outcomes will be duplicated for the pre-CR assessments, which will be

added into the regression analyses as an independent.

Table 5.1 Post Cardiac Rehabilitation Outcomes Descriptions

Cardiovascular Risk Factors	
Blood pressure post-CR	The variable is classified into 2 categories (Yes, No) for hypertension, i.e., systolic blood pressure ≥ 130 mmHg or diastolic blood pressure ≥ 80 mmHg for Asian ethnicity. At the same time, other ethnicities would be systolic blood pressure ≥ 140 mmHg or diastolic blood pressure ≥ 90 mm Hg.
Smoking post-CR	Patient's response to if they are smoking or not was classified into binary (Yes, No).
Physical activity (150 min/week) post-CR	Patients' responses were classified into 2 categories (No, Yes) to the question, "Do you take regular physical activity of at least 30 minutes duration on average 5 times a week (equivalent to 150 minutes over 7 days)?".
Obesity post-CR	Obesity was assessed as having BMI ≥ 25 Kg/m^2 for Asian ethnicity and BMI ≥ 30 Kg/m^2 for other ethnicities and coded (Yes, No).
Psychological health	
HADS-Anxiety post-CR	Patients' rates on HADS's anxiety component were classified into 2 categories (Borderline abnormal/Clinically Anxious, Normal). • Borderline abnormal/Clinically Anxious = 8-21 score. • Normal = 0-7.
HADS-Depression post-CR	Patients' rates on the Depression component of HADS were classified into 2 categories (Borderline abnormal/Clinically Depressed, Normal). • Borderline abnormal/Clinically Depressed = 8-21 score. • Normal = 0-7.
Feelings (Dartmouth) post-CR	An unhealthy and healthy response to the feelings component of the Dartmouth Coop Functional Assessment Chart was classified into 2 categories (No, Yes). • Unhealthy response = score 4-5 = No. • Healthy response = score 1-3 = Yes.
QOL (Dartmouth) post-CR	Unhealthy and healthy responses to the QOL component of the Dartmouth Coop Functional Assessment Chart were classified into 2 categories (No, Yes). • Unhealthy response = score 4-5 = No. • Healthy response = score 1-3 = Yes.
Physical fitness	
Physical fitness (Dartmouth) post-CR	Unhealthy and healthy responses to the Dartmouth Coop Functional Assessment Chart's physical fitness component were classified into 2 categories (No, Yes). • Unhealthy response = score 4-5 = No • Healthy response = score 1-3 = Yes
6MWT post-CR	Patient score after performing 6MWT expressed in a meter (m).
ISWT post-CR	Patient score after performing the ISWT expressed in m.

CR: cardiac rehabilitation. BMI: body mass index. Min: minute. HADS: Hospital Anxiety and Depression Scale. QOL: quality of life. 6MWT: 6 minutes walking test. ISWT: incremental shuttle-walk test.

The Asian ethnicity made up 6.2% (2,960 patients) of the study population, while the white ethnicity 87.2% (41,564 patients), black ethnicity 0.8% (394 patients) and other 5.8% (2,744 patients). Research and international guidelines state that Asian ethnicity is associated with a higher risk of developing cardiovascular diseases due to hypertension and obesity; thus, the diagnostic cut-points are lower specifically for them than the other ethnicities (Eastwood et al., 2015; National Institute for Health and Care Excellence, 2013). Hence, Asian ethnicity has a lower threshold for hypertension (Systolic blood pressure $\geq$ 130 mmHg or diastolic blood pressure $\geq$ 80 mmHg) as well as for obesity (BMI $\geq$ 25 Kg/m^2), and the variable of blood pressure and obesity were coded to reflect the appropriate threshold according to the ethnicity. The age factor was used as a continuous variable in the 2 previous chapters; however, in this chapter, the age factor was transformed into a categorical variable to ensure the regression's assumption of linearity of the logit. For linear regression, the independent multicategorical variables transformation to dichotomous variables was shown in Appendix N.

5.4 Data Analysis

Descriptive statistics were used for the initial analysis using count and percentages for categorical variables and mean and SD for continuous variables. Inferential statistics were used to compare categorical variables by conducting chi-square tests and independent samples t-tests to compare the means of 2 continuous variables. All statistical tests were considered statistically significant if the p-value <0.05. Also, there was reporting on achieving the minimal clinically significant difference (MCID) for 6MWT and ISWT.

Both logistic regressions and linear regression models were used to determine whether waiting time was associated with cardiac rehabilitation outcomes. For each model, there were adjustments for the dependent outcome's baseline (i.e., the outcome pre-CR) and patient factors, cardiac events factors, and CR delivery factors. Nine hierarchal logistic regression models were conducted for each of the binary outcomes (obesity, smoking,

physical activity (150 min/week), blood pressure, HADS-Depression, HADS-Anxiety, feelings (Dartmouth), QOL (Dartmouth), physical fitness (Dartmouth)). In addition, 2 linear regression models were used to examine the association between waiting time with the 2 continuous outcomes, i.e., 6MWT post-CR and ISWT post-CR. Each model was evaluated, and its assumption was assessed, as mentioned in the methodology, chapter 2, section 2.4.2.

5.5 Results

5.5.1 Patient Characteristics
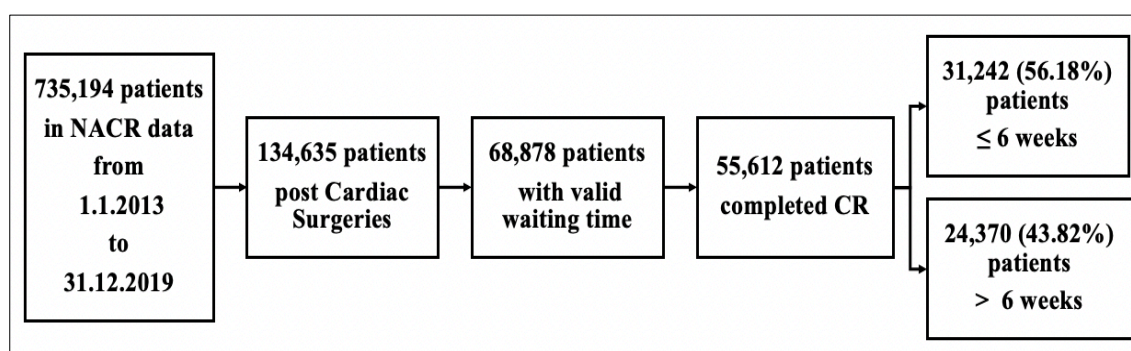
Figure 5.1 Flow Chart of the Study Sample

CR: cardiac rehabilitation.

The number of cases in the NACR database for the span of 7 years, from the beginning of 2013 until the end of 2019, was 735,194 patients. Patients who underwent median sternotomy surgeries for CABG, valve surgeries and combined CABG and valve surgeries were 134,635. This study found 68,878 patients with valid waiting times; among them, 55,612 patients completed CR. Further, there were 51.0% (31,242 patients) started CR early and had a shorter waiting time (≤ 6 weeks WT), while the other 43.8% (24,370 patients) started CR late with > 6 weeks WT (see Figure 5.1). Descriptive and inferential statistics were used to detail and explore the association between waiting time and patient characteristics.

Waiting time association with patient characteristics, including age, gender, ethnicity, partnership status, SES, and treatment types, was shown in Table 5.2. Each age group had a relatively equal representation between the 2 categories of waiting time. There was an

association between age and waiting time as the chi-square test was shown to be

significant χ^2 (3) = 121.2.

Table 5.2 Patient Characteristics

Patient characteristics		Waiting time		Chi-square	df	p-value*
		≤ 6 weeks WT	> 6 weeks WT			
		Count (%)	Count (%)			
Age	18-60 years old	8,211 (26.3)	5,560 (22.8)	121.2	3	<0.001
	61-67 years old	6,939 (22.2)	5,295 (21.7)			
	68-73 years old	7,571 (24.2)	6,074 (24.9)			
	74-100 years old	8,521 (27.3)	7,441 (30.5)			
Gender	Male	24,059 (77.8)	18,348 (75.9)	26.7	1	<0.001
	Female	6,865 (22.2)	5,816 (24.1)			
Ethnicity	White	23,429 (87.7)	18,135 (86.6)	13.3	1	<0.001
	Non-white	3,286 (12.3)	2,812 (13.4)			
Partnership status	Partnered	17,733 (56.8)	13,952 (57.3)	1.3	1	0.246
	Not partnered	13,509 (43.2)	10,418 (42.7)			
SES	First quintile	3,232 (12.6)	2,539 (12.1)	11.8	4	0.019
	Second quintile	4,193 (16.4)	3,272 (15.6)			
	Third quintile	5,086 (19.9)	4,137 (19.8)			
	Fourth quintile	5,941 (23.2)	5,066 (24.2)			
	Fifth quintile	7,125 (27.9)	5,906 (28.2)			
Treatment types	CABG	17,653 (56.5)	14,589 (59.9)	113.7	2	<0.001
	Valve surgeries	10,327 (33.1)	7,029 (28.8)			
	CABG/Valve	3,262 (10.4)	2,752 (11.3)			

* Significant if p-value < 0.05.
%: percentage. CR: cardiac rehabilitation. df: degrees of freedom. WT: waiting time. SES: socioeconomic status.

Between the 2 categories of waiting time, i.e., ≤ 6 weeks WT and > 6 weeks WT, men made up the majority with 77.8% and 75.9%, accordingly. The chi-square test showed a significant association between gender and waiting time χ^2 (1) = 26.7. Moreover, ethnicity was also associated with waiting time χ^2 (1) = 13.3, as patients with white ethnicity made the majority by 87.7% in ≤ 6 weeks WT and 86.6% in > 6 weeks WT. While most of the patients were partnered in the 2 categories of waiting time, partnership status had a nonsignificant association. Patients classified according to their SES were divided approximately equally between the groups of waiting time of ≤ 6 weeks WT and > 6 weeks WT by 12.6% and 12.1% for the lowest quintile, 16.4% and 15.6% for the second quintile, 19.9% and 19.8% for the third quintile, 23.2% and 24.2% for the fourth quintile and 27.9% and 28.2% for the fifth quintile. Further, there was an association between waiting time and SES as the chi-square test was significant χ^2 (4) = 11.8. Also, there was a significant association between waiting time and treatment types χ^2 (2) = 113.7, which was predominantly post-CABG.

5.5.2 Cardiovascular Risk Factors Outcomes

Tables 5.3 and 5.4 show cross-tabulation analysis between cardiovascular risk factors outcomes pre-CR and post-CR outcomes in relation to WT groups. The majority of the patients with obesity pre-CR had remained in the obesity level post-CR in both waiting times, i.e., 3,974 (89.5%) in the ≤ 6 weeks WT group and 3,136 (90.3%) in the > 6 weeks WT group. While the number of patients with obesity pre-CR who become non-obese was slightly better in the ≤ 6 weeks WT group, with 466 (10.5%) compared to the > 6 weeks WT group with 337 (9.7%). Within the ≤ 6 weeks WT group and post-CR, a higher percentage of the patients ceased smoking by 234 (44.7%) than in the > 6 weeks WT group with 141 (41.7%). In both waiting times, the number of patients who retained high blood pressure was 79.0%, while those who recovered to the normal blood pressure level formed 21.0%. Patients who were not physically active pre-CR and became active post-

CR formed the majority, with 5,946 (68.4%) in the ≤ 6 weeks WT group and 4,144 (65.2%) in the > 6 weeks WT group.

Table 5.3 Cardiovascular Risk Factors Outcomes vs Waiting Times (Part 1)

Pre-CR	Post-CR	Waiting Time			
		≤ 6 weeks WT Count (%)		> 6 weeks WT Count (%)	
		Yes	No	Yes	No
Obesity (BMI ≥ 30, ≥ 25 kg/m² for Asian ethnicity)	Yes	3,974 (89.5)	466 (10.5)	3,136 (90.3)	337 (9.7)
	No	660 (4.9)	12,958 (95.2)	501 (4.7)	10,077 (95.3)
Smoking	Yes	290 (55.3)	234 (44.7)	197 (58.3)	141 (41.7)
	No	126 (0.7)	19,392 (99.4)	79 (0.5)	14,537 (99.5)
Blood pressure (< 140/90, < 130/80 for Asian ethnicity)	Yes	11,005 (78.7)	2,984 (21.3)	7,587 (79.2)	1,992 (20.8)
	No	2,362 (43.5)	3,064 (56.5)	1,922 (40.8)	2,784 (59.2)

%: percentage. CR: cardiac rehabilitation. WT: waiting time. BMI: body mass index.

Table 5.4 Cardiovascular Risk Factors Outcomes vs Waiting Times (Part 2)

Pre-CR	Post-CR	Waiting Time			
		≤ 6 weeks WT Count (%)		> 6 weeks WT Count (%)	
		No	Yes	No	Yes
Physical activity (> 150 min/week)	No	2,751 (31.6)	5,946 (68.4)	2,212 (34.8)	4,144 (65.2)
	Yes	646 (8.4)	7,091 (91.7)	520 (9.3)	5,069 (90.7)

%: percentage. CR: cardiac rehabilitation. WT: waiting time. Min: minute.

5.5.2.1 Factors Associated With Cardiovascular Risk Factors Outcomes

Four logistic regression models were conducted where the dependent variables were each of the cardiovascular risk factors outcomes post-CR second assessment (i.e., obesity, smoking, physical activity (150 min/week), blood pressure). The models were built in 5 blocks as the first block with the enter method and 2 variables, cardiovascular risk factors outcomes post-CR first assessments and waiting time. Then, the backward elimination method was used with the other 4 blocks with treatment type and patient factors making the second block, the cardiac-event factors the third block, and the CR delivery factors between the fourth and the fifth block.

5.5.2.1.1 Factors Associated With Obesity

Obesity was tested with the categorical variable of BMI post-CR as an outcome, and 24 independent factors formed of BMI pre-CR, waiting time, patient factors, cardiac-event factors, and CR delivery factors. The number of cases included in the analysis was 13,370 patients. The final model was statistically significant, χ^2 (12) = 9,377.831, p-value < 0.05, with −2 log likelihood (5,708.247), explaining 75.5% (Nagelkerke R^2) of variance and correctly classifying 94.1% of cases (see Appendix O). Hosmer-Lemeshow goodness-of-fit, χ^2 (8) = 11.524, p-value > 0.05, which means the model is a good fit. The ROC curve test indicates that the model has a strong predictive ability with an AUC of 0.934 (SE = 0.002, 95% CI: 0.929, 0.939). The classification performance measures were computed at the default cut-off point of 0.50 for specificity (86.30%) and the model's sensitivity (96.77%). The assumptions of the logistic regression model were assessed and met.

BMI was primarily analysed as a dichotomous variable to account for the diagnostic threshold of obesity of BMI ≥ 25 Kg/m^2 for Asian ethnicity and BMI ≥ 30 Kg/m^2 for other ethnicities in line with national guidelines and existing research (NICE, 2015; Eastwood et al., 2015; National Institute for Health and Care Excellence, 2013). For the purpose of testing weight loss post-CR and its relationship to waiting time and other

independent factors, BMI was examined as a continuous variable. The rationale for testing BMI in two formats was to allow for small, within-group changes that may be missed in the categorised version of BMI. Multiple linear regression was conducted to examine the relationship between BMI post-CR and several independent factors. The model showed there was n = 13,370 cases, the result of the analysis of variance was $F_{(36, 13,333)} = 1,993.975$, p-value < 0.001 and $R^2 = 843$, which means that the model could explain 84.0% of the variance in the BMI post-CR. The linear regression model's assumptions were examined, and it showed a violation of the normality assumption, homoscedasticity, and the absence of unusual cases, which render the results of linear regression invalid and thus not included in the thesis.

The results from the logistic regression (seen in Table 5.5) show that only 6 factors were significant among the 24 independent factors. The association between not being obese after completing CR and waiting time to start the CR programme, categorised into 2 variables, $\leq$ 6 weeks WT and > 6 weeks WT, was nonsignificant. However, the baseline measurements of BMI during pre-CR assessment had a significant association with BMI post-CR. Having a BMI under 30 kg/m^2 (or under 25 kg/m^2 for Asian) before the start of CR increase the probability of completing the CR not being obese by 176.38 times (95% CI: 151.67, 205.11). When compared to the youngest age category (18-60 years old), the age groups of 68-73 years old and 74-100 years old were found to have a positive association with not being obese post-CR by OR: 1.68 (95% CI: 1.36, 2.07) and OR: 2.18 (95% CI: 1.76, 2.68) respectively. Among the subcategories of SES, patients in the third and fifth quintiles had a higher probability of not being obese post-CR by 35.0% and 42.0%, correspondingly, compared to patients in most deprived areas socioeconomically. Patients with diabetes mellitus were less likely to be not obese post-CR by 0.64 times (95% CI: 0.54, 0.76). Similarly, patients with hyperlipidaemia had a decrease in the likelihood of BMI < 30 kg/m^2 (or <25 kg/m^2 for Asians) by CR by 14.0%.

Table 5.5 Logistic Regression Results for Obesity Post-CR

Factors (reference)		OR	95% CI		p-value*
			Lower	Upper	
Waiting time (≤ 6 weeks WT)	> 6 weeks WT	0.93	0.80	1.08	0.322
BMI pre-CR (≥ 25 for Asian ethnicity and ≥ 30 for other ethnicities)	BMI < 25 for Asian ethnicity and < 30 for other ethnicities)	176.38	151.67	205.11	<0.001
Age (18-60 years old)	61-67 years old	1.14	0.93	1.41	0.200
	68-73 years old	1.68	1.36	2.07	<0.001
	74-100 years old	2.18	1.76	2.68	<0.001
Ethnicity (White)	Non-white	2.25	1.79	2.84	<0.001
SES (First quintile most deprived)	Second quintile	0.95	0.71	1.26	0.723
	Third quintile	1.35	1.02	1.78	0.037
	Fourth quintile	1.27	0.97	1.65	0.084
	Fifth quintile	1.42	1.10	1.85	0.008
Diabetes mellitus (No)	Yes	0.64	0.54	0.76	<0.001
Hyperlipidaemia (No)	Yes	0.86	0.74	0.99	0.046

* Significant if p-value < 0.05.
Note: Not significant variables (waiting time, treatment type, gender, partnership status, previous CR, hospital length of stay, angina, hypertension, anxiety, depression, family history of CVD, number of comorbidities, a diagnosis of ≥ 2 cardiac events, confirmed joining date, referring health professional, CR delivery mode, multidisciplinary team , BACPR certified programme).
BMI: body mass index. CR: cardiac rehabilitation. WT: waiting time. OR: odds ratio. CI: confident intervals. SES: socioeconomic status.

5.5.2.1.2 Factors Associated With Smoking

Like obesity, smoking was analysed with the variable of smoking post-CR as (Yes, No) as dependent and smoking pre-CR as an independent factor, in addition to waiting time and the 24 other factors. There were 14,825 cases included in the regression analysis. The final model was significant χ^2 (7) = 1,226.803, p-value < 0.05 with −2 log likelihood (1,463.321), explaining 47.9% (Nagelkerke R^2) of variance and correctly classifying 98.6 % of cases (see Appendix P). The statistic of Hosmer-Lemeshow goodness-of-fit was found to be significant χ^2 (7) = 33.546, p-value < 0.05, which could be due to a large number of the sample (Kramer and Zimmerman, 2007). The ROC curve test indicates that the model has a strong predictive ability with an AUC of 0.934 (SE = 0.002, 95% CI: 0.929, 0.939). The measures of classification performance were computed at the default cut-off point of 0.50 for the model's specificity (50.56%) and sensitivity (99.45%). To increase specificity, a new cut-off point was chosen (0.8), which resulted in a specificity (71.00%) and a sensitivity (98.69%). The assumptions of the logistic regression model were assessed and met.

Smoking status at post-CR assessment showed no significant association with waiting time. Among the other twenty-three factors, only five were found to have a significant association with smoking post-CR assessment (smoking pre-CR, marital status, depression, CR delivery mode and CR referred by) (see Table 5.6).

Patients who were non-smokers before the start of CR are 215.339 times more likely to be non-smokers after completing CR (95% CI: 155.424, 298.352). Compared to not partnered, partnered patients have a decreased likelihood of being non-smokers at post-CR assessment by odds of 0.696 (95% CI: 0.510, 0.949). Also, patients diagnosed with depression negatively associate smoking cessation as they are less probability by OR: 0.481 (95% CI: 0.287, 0.807). Regarding the CR delivery mode, the analysis showed that having self-delivered as a form of approach to CR would associate negatively with

smoking cessation by 0.618 times (95% CI: 0.417, 0.916). Compared to a consultant or cardiac nurse, being referred to CR by GP or primary care nurse increased the probability of being a non-smoker at post-CR assessments by OR: 4.391 (95% CI: 2.517, 7.662).

Table 5.6 Logistic Regression Results for Smoking Post-CR

Factors (reference)		OR	95% CI		p-value*
			Lower	Upper	
Waiting time (≤ 6 weeks WT)	**> 6 weeks WT**	1.37	0.98	1.92	0.069
Smoking pre-CR (Yes)	**No**	215.34	155.42	298.35	<0.001
Partnership status (Not partnered)	**Partnered**	1.44	1.05	1.96	0.022
Depression (No)	**Yes**	0.48	0.29	0.81	0.006
CR delivery mode (Supervised delivery)	**Self-delivered**	0.62	0.42	0.92	0.016
Referring health professional (Consultant/cardiac nurse)	**GP/primary care nurse**	4.39	2.52	7.66	<0.001
	Other	1.36	0.78	2.35	0.277

* Significant if p-value < 0.05.
Note: Not significant variables (waiting time, treatment type, age, gender, ethnicity, socioeconomic status (SES), previous CR, hospital length of stay, angina, diabetes mellitus, hypertension, anxiety, family history of CVD, hyperlipidaemia, number of comorbidities, a diagnosis of ≥ 2 cardiac events, confirmed joining date, multidisciplinary team, BACPR certified programme).
CR: cardiac rehabilitation. WT: waiting time. OR: odds ratio. CI: confident intervals. GP: general practitioner.

5.5.2.1.3 Factors Associated With Physical Activity (150 min/week)

Twenty-four independent variables pre-CR assessments, waiting time, patient factors, cardiac events factors and CR delivery factors were used to analyse physical activity (150 min/week) where physical activity post-CR assessments were the outcome. The final model was significant χ^2 (25) = 1,200.333, p-value < 0.05 with −2 log likelihood (11,238.456), explaining 14.7% (Nagelkerke R^2) of variance and correctly classifying 78.8 % of cases (see Appendix Q). Hosmer-Lemeshow goodness-of-fit, χ^2 (8) = 6.250, p-value > 0.05, which means the model is a good fit. The ROC curve test indicates that the model has an acceptable predictive ability with an AUC of 0.715 (SE = 0.005, 95% CI: 0.706, 0.724). The measures of classification performance were computed at the default cut-off point of 0.50 for the specificity of the model (1.61%) and the sensitivity (99.54%). To increase specificity, a new cut-off point was chosen (0.72), which resulted in specificity (62.51%) and sensitivity (69.51%). The assumptions of the logistic regression model were assessed and met.

The significant independent factors associated with physical activity (150 min/week) post-CR are shown in Table 5.7. Unlike obesity and smoking, physical activity (150 min/week) appeared to have a significant association with waiting time. The analysis indicated that waiting > 6 weeks to start CR would decrease patients' likelihood of being physically active post-CR by 15.0%.

Further, there was a statistically significant relationship between the states of patients' physical activity (150 min/week) pre-CR and post-CR. The probability of practising physical activity (150 min/week) regularly at post-CR assessment would increase by 4.51 (95% CI: 4.0, 5.02) when patients were already active at pre-CR assessment. Being female patients or aged 74-100 years old showed a negative association with being physically active post-CR by 17.0% and 19.0%, respectively. Compared to people with the lowest SES (first quintile according to IMD score), patients with a better

socioeconomic status had a better likelihood of being physically active post-CR by 26.0% for the second quintile, 39.0% for the third quintile, 28.0% for fourth quintile and 49.0% for the fifth quintile.

Table 5.7 Logistic Regression Results for Physical activity (150 min/week) Post-CR

Factors (reference)		OR	95% CI		p-value*
			Lower	Upper	
Waiting time (≤ 6 weeks WT)	> 6 weeks WT	0.85	0.78	0.94	<0.001
Physical activity (150 min/week) pre-CR (No)	Yes	4.51	4.06	5.02	<0.001
Age (18-60 years old)	61-67 years old	0.92	0.80	1.06	0.267
	68-73 years old	1.05	0.91	1.20	0.531
	74-100 years old	0.83	0.72	0.94	0.004
Gender (Male)	Female	0.81	0.73	0.90	<0.001
SES (First quintile most deprived)	Second quintile	1.26	1.05	1.50	0.012
	Third quintile	1.39	1.17	1.65	<0.001
	Fourth quintile	1.28	1.09	1.51	0.003
	Fifth quintile	1.49	1.27	1.75	<0.001
Hospital length of stay (≤ 6 days)	7-9 days	1.03	0.90	1.18	0.653
	10-16 days	0.94	0.81	1.08	0.389
	≥ 17 days	0.79	0.70	0.89	<0.001
Diabetes mellitus (No)	Yes	0.83	0.74	0.93	<0.001
Hypertension (No)	Yes	1.12	1.01	1.24	0.037
Family history of CVD (No)	Yes	1.15	1.03	1.28	0.016
Hyperlipidaemia (No)	Yes	1.12	1.01	1.24	0.039
Number of comorbidities (No comorbidity)	1-2 comorbidities	0.82	0.63	1.07	0.144
	≥ 3 comorbidities	0.69	0.52	0.93	0.013
Confirmed joining date (No)	Yes	0.85	0.74	0.97	0.019
Referring health professional (Consultant/cardiac nurse)	GP/primary care nurse	1.03	0.72	1.48	0.878
	Other	0.80	0.70	0.92	0.002
Multidisciplinary team (No)	Yes	0.86	0.75	0.98	0.024

* Significant if p-value < 0.05.
Note: Not significant variables (treatment type, ethnicity, partnership status, previous CR, angina, anxiety, depression, a diagnosis of ≥ 2 cardiac events, CR delivery mode, BACPR certified programme). BMI: body mass index. CR: cardiac rehabilitation. WT: waiting time. OR: odds ratio. CI: confident intervals. SES: socioeconomic status. CVD: cardiovascular disease. GP: general practitioner.

Among the hospital length of stay's subcategories, only ≥ 17 days of hospitalisation significantly negatively associated physical activity (150 min/week) post-CR by 21.0%. While the comorbidities of angina, anxiety and depression had a nonsignificant association with physical activity (150 min/week), the rest of the comorbidities were significant, i.e., diabetes mellitus, hypertension, family history of CVD and hyperlipidaemia. There was a decrease in the likelihood of being physically active post-CR for patients with a history of diabetes mellitus by an odd of 0.83 (95% CI: 0.74, 0.93). Differently, there was an increased likelihood of being physically active post-CR for patients with a comorbidity of hypertension (OR = 1.12), family history of CVD (OR = 1.15) and hyperlipidaemia (OR = 1.12). Three or more comorbidities were associated negatively with being physically active post-CR by OR: 0.69 (95% CI: 0.52, 0.93). Furthermore, the analysis showed that having a confirmed joining date is also negatively associated with physical activity (150 min/week) post-CR by odds of 15.0%. The analysis also revealed decreased chances of physical activity post-CR when patients were referred to CR by "others" by 20.0% or when they participated in a CR programme conducted by a multidisciplinary team by 14.0%.

5.5.2.1.4 Factors Associated With Blood Pressure

This logistic regression had the blood pressure at post-CR as a dependent variable and waiting time, blood pressure at pre-CR, patient factors, cardiac events factors, and CR delivery factors as independent variables. The final model was significant χ^2 (8) = 48.694, p-value < 0.05 with −2 log likelihood (15,385.317), explaining 21.6% (Nagelkerke R^2) of variance and correctly classifying 72.6 % of cases (see Appendix R). The statistic of Hosmer-Lemeshow goodness-of-fit was found to be significant χ^2 (8) = 48.694, p-value < 0.05, which could be due to the large number of the sample (Kramer and Zimmerman, 2007). The ROC curve test indicates that the model has an acceptable predictive ability with an AUC of 0.746 (SE = 0.004, 95% CI: 0.739, 0.753). The measures of classification

performance were computed at the default cut-off point of 0.50 for the model's specificity (85.10%) and sensitivity (46.96%). To increase sensitivity, a new cut-off point was chosen (0.276), which resulted in specificity (5.59%) and sensitivity (70.88%). The assumptions of the logistic regression model were assessed and met.

The results of logistics regression to assess the association between waiting time and blood pressure post-CR are shown in Table 5.8. There was a nonsignificant association between waiting time and not having hypertension at post-CR assessment. Not having hypertension at pre-CR had a positive association with not being hypertensive at post-CR assessment by 4.53 times (95% CI: 4.19, 4.90). When comparing treatment types to patients post-CABG, patients who underwent combined CABG and valve surgeries had an increased in the likelihood of completing CR with blood pressure measurement below the hypertension levels by 15.0%. Patients aged 61 years and older, when compared to the youngest age category, had a better probability of not being with high blood pressure post-CR, i.e., 61-67 years old (OR: 1.27), 68-73 years old (OR: 1.52) and 74-100 years old (OR: 1.57).

Patients from non-white ethnicities had lower odds of completing CR without being hypertensive by 58.0%. Unlike the second and fifth, the third and fourth subcategories of SES showed a positive association with not having hypertension post-CR by 28.0% and 16.0%, respectively. A prolonged hospitalisation that exceeded 16 days decreased the probability of not having high blood pressure post-CR (OR: 0.84, 95% CI: 0.76, 0.92). The likelihood of not having high blood pressure post-CR increased for a patient with diabetes mellitus (OR: 1.21) or hypertension (OR: 1.73), while it decreased for a patient with anxiety (OR: 0.76) or hyperlipidaemia (OR: 0.90). Patients with ≥ 3 comorbidities were less likely to complete CR with not being with high blood pressure by an odds ratio of 0.74 (95% CI: 0.59, 0.92). CR programmes certified by BACPR had a higher

probability of patients not having high blood pressure post-CR (OR: 1.10, 95% CI: 1.01, 1.20).

Table 5.8 Logistic Regression Results for Blood Pressure Post-CR

Factors (reference)		OR	95% CI		p-value*
			Lower	Upper	
Waiting time (≤ 6 weeks WT)	**> 6 weeks WT**	1.01	0.93	1.09	0.852
Blood pressure pre-CR (Yes)	**No**	4.53	4.19	4.91	<0.001
Treatment type (CABG)	**Valve Surgeries**	1.00	0.91	1.10	0.997
	CABG/valve	1.15	1.02	1.31	0.027
Age (18-60 years old)	**61-67 years old**	1.27	1.13	1.44	<0.001
	68-73 years old	1.52	1.36	1.71	<0.001
	74-100 years old	1.57	1.40	1.76	<0.001
Ethnicity (White)	**Non-white**	0.42	0.37	0.48	<0.001
SES (First quintile most deprived)	**Second quintile**	1.05	0.90	1.23	0.521
	Third quintile	1.28	1.10	1.48	<0.001
	Fourth quintile	1.16	1.01	1.34	0.039
	Fifth quintile	1.02	0.89	1.18	0.749
Hospital length of stay (≤ 6 days)	**7-9 days**	1.00	0.90	1.12	1.000
	10-16 days	1.01	0.90	1.14	0.850
	≥ 17 days	0.84	0.76	0.92	<0.001
Diabetes mellitus (No)	**Yes**	1.21	1.10	1.34	<0.001
Hypertension (No)	**Yes**	1.73	1.59	1.89	<0.001
Anxiety (No)	**Yes**	0.76	0.62	0.92	0.006
Hyperlipidaemia (No)	**Yes**	0.90	0.83	0.99	0.025
Number of comorbidities (No comorbidity)	**1-2 comorbidities**	0.82	0.67	1.01	0.060
	≥ 3 comorbidities	0.74	0.59	0.92	0.007
BACPR certified programme (No)	**Yes**	1.10	1.01	1.20	0.027

* Significant if p-value < 0.05.

Note: Not significant variables (waiting time, gender, partnership status, previous CR, angina, depression, family history of CVD, a diagnosis of ≥ 2 cardiac events, confirmed joining date, referring health professional, CR delivery mode, multidisciplinary team).

CABG: coronary artery bypass grafting. BMI: body mass index. BACPR: British Association for Cardiovascular Prevention and Rehabilitation. CR: cardiac rehabilitation. WT: waiting time. OR: odds ratio. CI: confident intervals. SES: socioeconomic status.

5.5.3 Psychological Health Factors Outcomes

Tables 5.9 and 5.10 show cross-tabulation analysis between psychological health factors outcomes pre-CR and post-CR outcomes in relation to WT groups. While 92.6% of patients with normal anxiety levels pre-CR remained normal post-CR, 4.0% of patients who were borderline abnormal/ clinically anxious pre-CR became normal post-CR in the ≤ 6 weeks WT group compared to 44.7% in the > 6 weeks WT group. Similarly, with depression, 1,700 (66.9%) cases classified as borderline abnormal/ clinically depressed pre-CR became normal post-CR within ≤ 6 weeks WT group, which was higher than 1,197 (59.8%) cases within > 6 weeks WT group.

For feelings (Dartmouth), there was no noticeable difference between the WT groups, with the majority with healthy feelings (Dartmouth) pre-CR reported a similar level of healthy feelings (Dartmouth) post-CR by 11,112 (95.6%) patients and 8,580 (95.4%) patients for ≤ 6 weeks WT and > 6 weeks WT, respectively.

Table 5.9 Psychological Health Factors Outcomes vs Waiting Times (Part 1)

Pre-CR / Post-CR		Waiting Time			
		≤ 6 weeks WT Count (%)		> 6 weeks WT Count (%)	
		Borderline/ Clinically	Normal	Borderline/ Clinically	Normal
HADS-Anxiety	**Borderline abnormal/ Clinically Anxious**	1,538 (52.0)	1,421 (48.0)	1,340 (55.3)	1,084 (44.7)
	Normal	862 (7.4)	10,721 (92.6)	703 (7.7)	8,411 (92.3)
HADS-Depression	**Borderline abnormal/ Clinically Depressed**	843 (33.1)	1,700 (66.9)	806 (40.2)	1,197 (59.8)
	Normal	481 (4.0.)	11,515 (960)	394 (4.1)	9,129 (95.9)

%: percentage. CR: cardiac rehabilitation. HADS: Hospital Anxiety and Depression Scale. WT: waiting time.

Table 5.10 Psychological Health Factors Outcomes vs Waiting Times (Part 2)

Pre-CR	Post-CR	Waiting Time			
		≤ 6 weeks WT Count (%)		> 6 weeks WT Count (%)	
		Unhealthy	Healthy	Unhealthy	Healthy
Feelings (Dartmouth)	Unhealthy	396 (29.4)	950 (70.6)	355 (32.0)	755 (68.0)
	Healthy	507 (4.4)	11,112 (95.6)	409 (4.6)	8,580 (95.4)
QOL (Dartmouth)	Unhealthy	67 (13.8)	417 (86.2)	47 (12.7)	324 (87.3)
	Healthy	177 (1.4)	12,304 (98.6)	137 (1.4)	9,591 (98.6)

%: percentage. CR: cardiac rehabilitation. WT: waiting time. QOL: quality of life.

However, when comparing the number of patients who had unhealthy feelings (Dartmouth) pre-CR and became healthy post-CR, ≤ 6 weeks WT group had a slightly better improvement with 950 (70.6%) than > 6 weeks WT group with 755 (68.0%). Likewise, for healthy QOL (Dartmouth) pre-CR, there were 12,304 (98.6%) cases that continued to be healthy post-CR within ≤ 6 weeks WT, with 9,591 (98.6%) unhealthy QOL (Dartmouth) cases pre-CR that remained unhealthy post-CR in > 6 weeks WT group. There was a slight difference between the two WT groups for unhealthy QOL (Dartmouth) pre-CR who recovered to be healthy post-CR with 417 (86.2%) for short WT and 324 (87.3%) for longer WT.

5.5.3.1 Factors Associated With Psychological Health Factors Outcomes

Each of the psychological health factors outcomes post 2nd CR assessment were analysed as dependent factors using logistic regression, i.e., 4 models for HADS-Anxiety, HADS-Depression, feelings (Dartmouth), and QOL (Dartmouth). Each model was constructed similarly with 5 blocks of independent variables, the enter method was used in the first block, and the backward elimination method was used with the other 4 blocks. The

models' blocks were formed as follows; block 1: psychological health factors outcomes post-CR first assessments and waiting time, block 2: treatment type and patient factors, block 3: cardiac-event factors, block 4: CR delivery factors (referring health professional and CR delivery mode), block 5: CR delivery factors (multidisciplinary team and BACPR certified programme).

5.5.3.1.1 Factors Associated With HADS-Anxiety

Anxiety was analysed with the variable HADS-Anxiety post-CR as an outcome, and 24 independent factors formed of pre-CR HADS-Anxiety, waiting time, patient factors, cardiac-event factors, and CR delivery factors. The number of cases included in the analysis was 11,207 patients. The final model was statistically significant, $\chi^2 (14) = 2,445.158$, p-value < 0.05, with -2 log likelihood (7,797.805), explaining 32.7% (Nagelkerke R^2) of variance and correctly classifying 85.2% of cases (see Appendix S). Hosmer-Lemeshow goodness-of-fit, $\chi^2 (8) = 18.140$, p-value < 0.05, which could be due to a large sample (Kramer and Zimmerman, 2007). The ROC curve test indicates that the model has a strong predictive ability with an AUC of 0.810 (SE = 0.005, 95% CI: 0.801, 0.820). The measures of classification performance were computed at the default cut-off point of 0.50 for the specificity of the model (64.8%) and the sensitivity (43.3%). To increase sensitivity, a new cut-off point was chosen (0.8), which resulted in specificity (65.3%) and sensitivity (88.0%). The assumptions of the logistic regression model were assessed and met.

Table 5.11 shows waiting time and significant independent factors associated with HADS-Anxiety post-CR. Waiting time had a nonsignificant association with HADS-Anxiety post-CR. On the other hand, pre-CR HADS-Anxiety was significant as patients classified as normal pre-CR would have 12.06 (95% CI: 10.74, 13.54) times more likely to be normal post-CR.

Table 5.11 Logistic Regression Results for HADS-Anxiety Post-CR

Factors (reference)		OR	95% CI		p-value*
			Lower	Upper	
Waiting time (≤ 6 weeks WT)	> 6 weeks WT	0.89	0.79	1.00	0.050
Pre-CR HADS-Anxiety (Borderline abnormal/Clinically Anxious)	Normal	12.06	10.74	13.54	<0.001
Age (18-60 years old)	61-67 years old	1.29	1.10	1.51	0.002
	68-73 years old	1.55	1.32	1.82	<0.001
	74-100 years old	1.44	1.23	1.69	<0.001
Gender (Male)	Female	0.71	0.62	0.81	<0.001
Ethnicity (White)	Non-white	0.75	0.64	0.88	<0.001
SES (First quintile most deprived)	Second quintile	0.99	0.79	1.23	0.901
	Third quintile	1.23	1.00	1.52	0.053
	Fourth quintile	1.22	1.00	1.50	0.054
	Fifth quintile	1.35	1.10	1.64	0.004
Previous CR (Previous CR)	No previous CR	0.79	0.63	0.98	0.031
Anxiety (No)	Yes	0.65	0.51	0.83	<0.001
Depression (No)	Yes	0.53	0.42	0.68	<0.001

* Significant if p-value < 0.05.
Note: Not significant variables (waiting time, treatment type, partnership status, hospital length of stay, angina, diabetes mellitus, hypertension, family history of CVD, hyperlipidaemia, number of comorbidities, a diagnosis of ≥ 2 cardiac events, confirmed joining date, referring health professional, CR delivery mode, multidisciplinary team, BACPR certified programme).
CR: cardiac rehabilitation. WT: waiting time. OR: odds ratio. CI: confident intervals. HADS: Hospital Anxiety and Depression Scale. SES: socioeconomic status.

When compared to the youngest age group (18-60 years old), the other 3 age groups showed a positive association with completing CR being normal on the HADS-Anxiety scale starting with 68-73 years old by OR: 1.55 (95% CI: 1.32, 1.82), age group 74-100 years old by OR: 1.44 (95% CI: 1.23, 1.69) then the age group 61-67 years old by OR: 1.29 (95% CI: 1.10, 1.51). Unlike age, gender showed a negative association where being

female decreased the odds of being in the normal range of HADS-Anxiety post-CR by 0.709 times (95% CI: 0.622, 0.808). Likewise, non-white, compared to white ethnicity, had a lower probability of completing CR being normal by 39.0%. Compared to the first quintile, none of the other quintiles of the SES was significant except for the fifth quintile, which has a better chance of being normal post-CR 35.0%. There was a negative association between completing CR being normal and not having CR previously by OR: 0.79 (95% CI: 0.63, 0.98). Having either anxiety or depression as comorbidities would decrease the probabilities of being normal at HADS-Anxiety post-CR by OR: 0.65 (95% CI: 0.51, 0.83) and OR: 0.53 (95% CI: 0.42, 0.68).

5.5.3.1.2 Factors Associated With HADS-Depression

The association of pre-CR HADS-Depression, waiting time, patient factors, cardiac-event factors and CR delivery factors with HADS-Depression post-CR were investigated using logistic regression. The number of cases included in the analysis was 11,198 patients. The final model was significant χ^2 (22) = 1,601.925, p-value < 0.05 with −2 log likelihood (5,434.794), explaining 28.6% (Nagelkerke R^2) of variance and correctly classifying 90.70 % of cases (see Appendix T). Hosmer-Lemeshow goodness-of-fit, χ^2 (8) = 7.138, p-value > 0.05, which means the model is a good fit. The ROC curve test indicates the model has a strong predictive ability with an AUC of 0.810 (SE = 0.007, 95% CI: 0 0.806, 0.832). The classification performance measures were computed at the default cut-off point of 0.50 for the specificity of the model (14.1%) and the sensitivity (98.8%). To increase specificity, a new cut-off point was chosen (0.8), which resulted in specificity (62.8%) and sensitivity (88.6%). The assumptions of the logistic regression model were assessed and met.

The significant independent factors associated with being not depressed post-CR are shown in Table 5.12. Patients who waited for > 6 weeks to start CR had decreased probability of completing CR being normal at the HADS-Depression scale by 19.0%.

Table 5.12 Logistic Regression Results for HADS-Depression Post-CR

Factors (reference)		OR	95% CI		p-value*
			Lower	Upper	
Waiting time (≤ 6 weeks WT)	> 6 weeks WT	0.81	0.70	0.93	0.003
Pre-CR HADS-Depression (Borderline abnormal/Clinically depressed)	Normal	11.52	9.98	13.30	<0.001
Age (18-60 years old)	61-67 years old	1.27	1.04	1.55	0.021
	68-73 years old	1.51	1.23	1.85	<0.001
	74-100 years old	1.36	1.12	1.66	0.002
Ethnicity (White)	Non-white	0.65	0.54	0.78	<0.001
Partnership status (Not partnered)	Partnered	0.82	0.71	0.95	0.009
SES (First quintile most deprived)	Second quintile	1.06	0.82	1.37	0.676
	Third quintile	1.48	1.15	1.91	0.002
	Fourth quintile	1.23	0.96	1.57	0.097
	Fifth quintile	1.53	1.20	1.95	<0.001
Hospital length of stay (≤ 6 days)	7-9 days	0.81	0.66	1.01	0.059
	10-16 days	0.81	0.65	1.02	0.071
	≥ 17 days	0.66	0.55	0.80	<0.001
Anxiety (No)	Yes	0.77	0.65	0.92	0.003
Depression (No)	Yes	0.49	0.38	0.64	<0.001
Referring health professional (Consultant/cardiac nurse)	GP/primary care nurse	0.58	0.38	0.89	0.012
	Other	0.80	0.65	0.98	0.029

* Significant if p-value < 0.05.

Note: Not significant variables (treatment type, gender, previous CR, angina, diabetes mellitus, hypertension, family history of CVD, hyperlipidaemia, number of comorbidities, a diagnosis of ≥ 2 cardiac events, confirmed joining date, CR delivery mode, multidisciplinary team , BACPR certified programme).

CR: cardiac rehabilitation. WT: waiting time. OR: odds ratio. CI: confident intervals. HADS: Hospital Anxiety and Depression Scale. SES: socioeconomic status. GP: general practitioner.

The chances of patients with no depression, compared to those borderline abnormal/clinically depressed, had an increased odds to complete CR with no depression by OR: 11.52 (95% CI: 9.98, 13.30). With the youngest age group as reference, patients aged 68-73 years old had a higher chance of being not depressed post-CR by OR: 1.51 (95% CI: 1.23, 1.85) than the oldest age group, 74-100 years old by OR: 1.36 (95% CI: 1.12, 1.66), finally by OR: 1.27 (95% CI: 1.04, 1.55) for 61-67 years old. Both ethnicity and partnership status had a negative association with not having depression post-CR, with being non-white or partnered having a lower probability by OR: 0.65 (95% CI: 0.54, 0.78) and OR: 0.82 (95% CI: 0.71, 0.95), correspondingly. Regarding SES, patients from the fifth quintile on the IMD scale had increased chances of completing CR with no depression by 53.0% then patients from the third quintile by 48.0%. Only patients with the most prolonged period of hospitalisation were found to be less likely to be normal on the HADS-Depression scale by OR: 0.66 (95% CI: 0.55, 0.80). Being Anxious or depressed would lower patients' probability of not being depressed post-CR by 23.0% and 51.0%, respectively. The analysis showed that the odds of being not depressed post-CR reduced by 42.0% when referred to CR by a GP/primary care nurse and by 20.0% when referred by "other".

5.5.3.1.3 Factors Associated With Feelings (Dartmouth)

The associations of 24 independent variables and feelings (Dartmouth) post-CR were investigated by running a logistic regression analysis. The number of cases included in the analysis was 9,850 patients. The final model was significant χ^2 (11) = 750.531, p-value < 0.05 with −2 log likelihood (4,432.940), explaining 17.9% (Nagelkerke R^2) of variance and correctly classifying 92.6% of cases (see Appendix U). Hosmer-Lemeshow goodness-of-fit, χ^2 (8) = 9.260, p-value > 0.05, which mean the model is a good fit. The ROC curve test indicates that the model has a strong predictive ability with an AUC of 0.758 (SE = 0.007, 95% CI: 0.744, 0.773). The measures of classification performance

were computed at the default cut-off point of 0.50 for the specificity of the model (99.5%) and the sensitivity (5.5%). To increase sensitivity, a new cut-off point was chosen (0.930), which resulted in sensitivity (83.3%) and specificity (57.0%). The assumptions of the logistic regression model were assessed and met.

Table 5.13 Logistic Regression Results for Feelings (Dartmouth) Post-CR

Factors (reference)		OR	95% CI		p-value*
			Lower	Upper	
Waiting time (≤ 6 weeks WT)	> 6 weeks WT	0.92	0.79	1.09	0.335
Feelings (Dartmouth) pre-CR (Unhealthy)	Healthy	7.69	6.49	9.12	<0.001
Age (18-60 years old)	61-67 years old	1.52	1.21	1.90	<0.001
	68-73 years old	1.76	1.40	2.20	<0.001
	74-100 years old	1.85	1.48	2.30	<0.001
Gender (Male)	Female	0.80	0.67	0.97	0.021
Partnership status (Not partnered)	Partnered	0.73	0.62	0.86	<0.001
Previous CR (Previous CR)	No previous CR	0.69	0.52	0.91	0.009
Hypertension (No)	Yes	0.79	0.67	0.93	0.004
Anxiety (No)	Yes	0.55	0.41	0.74	<0.001
Depression (No)	Yes	0.52	0.38	0.69	<0.001

* Significant if p-value < 0.05.
Note: Not significant variables (waiting time, treatment type, ethnicity, socioeconomic status (SES), hospital length of stay, angina, diabetes mellitus, family history of CVD, hyperlipidaemia, number of comorbidities, a diagnosis of ≥ 2 cardiac events, confirmed joining date, referring health professional, CR delivery mode, multidisciplinary team , BACPR certified programme).
CR: cardiac rehabilitation. WT: waiting time. OR: odds ratio. CI: confident intervals.

The outcomes of the regression for feelings (Dartmouth) post-CR, including the waiting time results and the significant variables, are listed in Table 5.13. There was a

nonsignificant association between waiting time and feelings (Dartmouth) post-CR. Patients who were feeling healthy and did not complain of emotional distress pre-CR were more likely to feel healthy post-CR by 7.69 times (95% CI: 6.49, 9.12). Among the other significant variables, only age was found to have a positive association with feelings (Dartmouth) post-CR. Patients in the age group from 61-67 years old had a higher probability of reporting having healthy feelings (Dartmouth) post-CR by 52.0%, like for the other age groups 68-73 years old and 74-100 years old by 76.0% and 85.0%, respectively. Being female or partnered decreased the patient's chances of having healthy feelings (Dartmouth) post-CR by 0.80 times (95% CI: 0.67, 0.97) and 0.73 (95% CI: 0.62, 0.86), correspondingly. Patients who had not previously received CR have lower odds of healthy feelings (Dartmouth) by 31.0% post-CR. Being diagnosed with 1 of 3 comorbidities would diminish the patient's probability of completing CR with healthy feelings, i.e., hypertension by 21.0%, anxiety by 45.0%, and depression by 48.0%.

5.5.3.1.4 Factor Associated With QOL (Dartmouth)

Logistic regression was used to analyse the QOL (Dartmouth) association post-CR and predefined independent variables. The number of cases included in the analysis was 9,850 patients. The final model was significant χ^2 (10) = 152.577, p-value < 0.05 with −2 log likelihood (1,475.013), explaining 10.1% (Nagelkerke R^2) of variance and correctly classifying 98.4 % of cases (see Appendix V). Hosmer-Lemeshow goodness-of-fit, χ^2 (8) = 4.411, p-value > 0.05, which mean the model is a good fit. The ROC curve test indicates that the model has a strong predictive ability with an AUC of 0.719 (SE = 0.016, 95% CI: 0.687, 0.752). The measures of classification performance were computed at the default cut-off point of 0.50 for the specificity of the model (100%) and the sensitivity (0.0%). To increase sensitivity, a new cut-off point was chosen (0.980), which resulted in sensitivity (87.4%) and specificity (46.5%). The assumptions of the logistic regression model were assessed and met.

Table 5.14 Logistic Regression Results for QOL (Dartmouth) Post-CR

Factors (reference)		OR	95% CI		p-value*
			Lower	Upper	
Waiting time (≤ 6 weeks WT)	> 6 weeks WT	1.16	0.84	1.60	0.364
QOL (Dartmouth) pre-CR (Unhealthy)	Healthy	6.81	4.56	10.18	<0.001
Age (18-60 years old)	61-67 years old	1.98	1.23	3.19	0.005
	68-73 years old	1.65	1.06	2.56	0.027
	74-100 years old	1.50	0.99	2.28	0.057
Diabetes mellitus (No)	Yes	0.64	0.45	0.92	0.015
Anxiety (No)	Yes	0.44	0.26	0.74	0.002
Depression (No)	Yes	0.37	0.22	0.62	<0.001
Multidisciplinary team (No)	Yes	1.61	1.08	2.41	0.021

* Significant if p-value < 0.05.
Note: Not significant variables (waiting time, treatment type, gender, ethnicity, partnership status, socioeconomic status (SES), previous CR, hospital length of stay, angina, hypertension, family history of CVD, hyperlipidaemia, number of comorbidities, a diagnosis of ≥ 2 cardiac events, confirmed joining date, referring health professional, CR delivery mode, BACPR certified programme).
CR: cardiac rehabilitation. WT: waiting time. OR: odds ratio. CI: confident intervals. QOL: Quality of Life.

Table 5.14 shows the results for waiting time and the 6 significant variables. The model found a nonsignificant association between waiting time and QOL (Dartmouth) post-CR. Having healthy QOL (Dartmouth) pre-CR increases the probability of healthy QOL (Dartmouth) post-CR by 6.81 times (95% CI: 4.56, 10.18). The analysis revealed that age had a positive relationship with QOL (Dartmouth) post-CR, where the age group 61-67 years old were more likely to report healthy QOL post-CR by OR: 98.0% and for older patients (68-73 years old) by 65.0%. Patients had lower chances to complete CR with healthy QOL (Dartmouth) when they had diabetes mellitus by 36.0%, had anxiety by

56.0%, or had depression by 63.0%. CR operated by a multidisciplinary team improved the probability of healthy QOL (Dartmouth) post-CR by OR: 1.61 (95% CI: 1.08, 2.41).

5.5.4 Physical Fitness Factors Outcomes

Tables 5.15 and 5.16 show cross-tabulation between physical fitness factors outcomes and WT groups. For the ≤ 6 weeks WT group, there were 3,709 (92.9%) cases with healthy physical fitness (Dartmouth) pre-CR that remained healthy post-CR, while 6,453 (71.9%) unhealthy physical fitness (Dartmouth) pre-CR became healthy post-CR. Alike for the > 6 weeks WT, 3,576 (91.3%) patients with healthy physical fitness (Dartmouth) pre-CR continued to be healthy post-CR in the time 4,037 (65.3%) unhealthy pre-CR became healthy post-CR. The mean of 6MWT pre-CR measurements was 323.6 (SD = 115) m for the ≤ 6 weeks WT group and 320.9 (SD = 112) m for the > 6 weeks WT, with a nonsignificant difference between them. There was a significant difference between WT groups for the mean of the 6MWT post-CR with 397.0 (SD = 120) m for ≤ 6 weeks WT, which was higher than > 6 weeks WT (mean 389.5, SD = 119 m). The mean for the change between 6MWT measurements (pre-CR subtracted from post-CR) showed an increased mean for ≤ 6 weeks WT group by 73.4 (SD = 67) m compared to a mean of 68.6 (SD = 64) m for > 6 weeks WT, with a significant difference between them. Comparing the means for ISWT pre-CR within WT groups showed it was higher for ≤ 6 weeks WT (357.2, SD = 165 m) while it was (335.3, SD =153 m) with a significant difference between them. Similarly, ISWT post-CR means for ≤ 6 weeks WT was 477.4 (SD = 194) m and 431.6 (SD = 179) m for > 6 weeks WT, with a significant difference between the means. Further, the change between pre-CR and post-CR for ISWT was 120.2 (SD = 112) m for ≤ 6 weeks WT and 96.4 (SD = 99) m for > 6 weeks WT, with a significant difference.

Table 5.15 Physical Fitness Factors Outcomes vs Waiting Times (Part 1)

Pre-CR \ Post-CR		Waiting Time			
		≤ 6 weeks WT Count (%)		> 6 weeks WT Count (%)	
		Unhealthy	Healthy	Unhealthy	Healthy
Physical fitness (Dartmouth) pre-CR	Unhealthy	2,520 (28.1)	6,453 (71.9)	2,145 (34.7)	4,037 (65.3)
	Healthy	283 (7.1)	3,709 (92.9)	341 (8.7)	3,576 (91.3)

%: percentage. CR: cardiac rehabilitation. WT: waiting time.

Table 5.16 Physical Fitness Factors Outcomes vs Waiting Times (Part 2)

Physical Fitness Factors Outcomes	Waiting Time				
	≤ 6 weeks WT		> 6 weeks WT		p-value*
Continuous variables	Count	Mean (SD)	Count	Mean (SD)	
6MWT pre-CR (m)	2,674	323.6 (115)	1,857	320.9 (112)	0.419
6MWT post-CR (m)		397.0 (120)		389.5 (119)	0.037
6MWT change (m)		73.4 (67)		68.6 (64)	0.017
ISWT pre-CR (m)	4,703	357.2 (165)	3,185	335.3 (153)	<0.001
ISWT post-CR (m)		477.4 (194)		431.6 (179)	<0.001
ISWT change (m)		120.2 (112)		96.4 (99)	<0.001

* Significant if p-value < 0.05.
CR: cardiac rehabilitation. WT: waiting time. SD: standard deviation. ISWT: incremental shuttle-walk test. 6MWT: 6 minutes walking test. M: meter.

5.5.4.1 Factors Associated With Physical Fitness Factors Outcomes

For the categorical outcome of physical fitness (Dartmouth) post-CR, logistic regression was used as a dependent factor, while each of the 2 continuous outcomes of 6MWT post-CR and ISWT post-CR was analysed as dependent factors using multiple linear regression.

5.5.4.1.1 Factors Associated With Physical Fitness (Dartmouth)

Physical fitness (Dartmouth) was analysed with the variable physical fitness (Dartmouth) post-CR as an outcome, and 24 independent factors formed of physical fitness (Dartmouth) pre-CR, waiting time, patient factors, cardiac-event factors, and CR delivery factors. The number of cases included in the analysis was 9,850 patients. The final model was statistically significant, χ^2 (17) = 1,347.238, p-value < 0.05, with −2 log likelihood (9,138.126), explaining 19.5% (Nagelkerke R^2) of variance and correctly classifying 77.9% of cases (see Appendix W). Hosmer-Lemeshow goodness-of-fit, χ^2 (8) = 25.099, p-value < 0.05, which could be due to a large sample (Kramer and Zimmerman, 2007). The ROC curve test indicates that the model has a strong predictive ability with an AUC of 0.744 (SE = 0.005, 95% CI: 0.734, 0.755). The measures of classification performance were computed at the default cut-off point of 0.50 for the specificity of the model (14.7%) and the sensitivity (96.1%). To increase specificity, a new cut-off point was chosen (0.750), which resulted in specificity (65.4%) and sensitivity (69.2%). The assumptions of the logistic regression model were assessed and met.

The significant independent factors associated with physical fitness (Dartmouth) post-CR are shown in Table 5.17. There was a significant relationship between physical fitness (Dartmouth) post-CR and waiting times with patients with longer waiting times (> 6 weeks) less likely to have healthy physical fitness (Dartmouth) post-CR by OR: 0.77 (95% CI: 0.69, 0.85) compared to patients with the shorter waiting time.

Table 5.17 Logistic Regression Results for Physical fitness (Dartmouth) Post-CR

Factors (reference)		OR	95% CI		p-value*
			Lower	Upper	
Waiting time (≤ 6 weeks WT)	> 6 weeks WT	0.77	0.69	0.85	<0.001
Physical fitness (Dartmouth) Pre-CR (Unhealthy)	Healthy	4.11	3.59	4.71	<0.001
Age (18-60 years old)	61-67 years old	0.86	0.73	1.02	0.087
	68-73 years old	0.67	0.57	0.78	<0.001
	74-100 years old	0.36	0.31	0.42	<0.001
Gender (Male)	Female	0.52	0.46	0.58	<0.001
Ethnicity (White)	Non-white	0.59	0.51	0.69	<0.001
SES (First quintile most deprived)	Second quintile	1.29	1.06	1.57	0.012
	Third quintile	1.62	1.34	1.96	<0.001
	Fourth quintile	2.03	1.69	2.45	<0.001
	Fifth quintile	2.05	1.71	2.45	<0.001
Hospital length of stay (≤ 6 days)	7-9 days	1.04	0.90	1.21	0.599
	10-16 days	0.81	0.69	0.94	0.006
	≥ 17 days	0.78	0.68	0.89	<0.001
Diabetes mellitus (No)	Yes	0.63	0.56	0.70	<0.001
Depression (No)	Yes	0.78	0.62	0.98	0.035
CR delivery mode (Supervised delivery)	Self-delivered	0.77	0.67	0.88	<0.001

* Significant if p-value < 0.05.
Note: Not significant variables (treatment type, partnership status, previous CR, angina, hypertension, anxiety, family history of CVD, hyperlipidaemia, number of comorbidities, a diagnosis of ≥ 2 cardiac events, confirmed joining date, referring health professional, multidisciplinary team , BACPR certified programme).
CR: cardiac rehabilitation. WT: waiting time. OR: odds ratio. CI: confident intervals. SES: socioeconomic status.

Patients with healthy physical fitness (Dartmouth) pre-CR had a higher probability of being healthy post-CR by 4.11 times. Compared to 18-60, patients in the older age group (74-100 years old) had the lowest likelihood of being healthy post-CR by 64.0%, then patients in the older age group (68-73 years old) by 33.0%. Being female or non-white decreased the chances of being healthy post-CR on the physical fitness (Dartmouth) scale by OR: 0.52 (95% CI: 10.46, 0.58) and OR: 0.59 (95% CI: 0.51, 0.69), respectively. The analysis indicated there was a positive association between SES and physical fitness (Dartmouth) post-CR, whereas there was an improvement in the status, the odds of being healthy increased, i.e., second quintile OR: 1.29 (95% CI: 1.06, 1.57), third quintile OR: 1.62 (95% CI: 1.34, 1.96), fourth quintile OR: 2.03 (95% CI: 1.69, 2.45), fifth quintile OR: 2.05 (95% CI: 1.712.45). Also, the analysis showed that patients' probabilities of being healthy at physical fitness (Dartmouth) post-CR would be diminished with a longer period of hospitalisation by 19.0% for 10-16 days and by 22.0% for ≥ 17 days. Further, being diagnosed with diabetes mellitus or depression lowered the chances of being healthy at physical fitness (Dartmouth) post-CR by 37.0% and by 22.0%, correspondingly. Self-delivered CR had a lower likelihood of being healthy at physical fitness (Dartmouth) post-CR by OR: 0.77 (95% CI: 0.67, 0.88) than supervised delivery CR.

5.5.4.1.2 Factors Associated With 6MWT

Multiple linear regression was conducted to examine the relationship between 6MWT post-CR and several independent factors. The first time the model was run (n = 1,698), the result of the analysis of variance was $F_{(36, 1661)} = 122.815$, p-value < 0.001 and R^2 =0.727, which means that the model could explain 73.0% of the variance in the 6MWT post-CR. The linear regression model's assumptions were examined and fulfilled (Appendix X).

Table 5.18 Linear Regression Results for 6MWT Post-CR

Factors (reference)		Unstandardised Coefficients		95% CI	Standardised Coefficients	t-test	p-value*
		B	Std. Error		Beta		
6MWT pre-CR (continues) (m)		0.82	0.02	(0.79, 0.85)	0.81	56.5	<0.001
Waiting time (≤ 6 weeks WT)	> 6 weeks WT	−9.92	2.94	(−15.68, −4.15)	−0.05	−3.4	<0.001
Age (18-60 years old)	61-67 years old	−8.79	4.29	(−17.2, −0.39)	−0.03	−2.1	0.040
	68-73 years old	−12.82	4.05	(−20.77, −4.88)	−0.05	−3.2	0.002
	74-100 years old	−29.18	4.07	(−37.15, −21.21)	−0.13	−7.2	<0.001
Gender (Male)	Female	−8.25	3.36	(−14.84, −1.66)	−0.03	−2.4	0.014
Diabetes mellitus (No)	Yes	−10.17	3.45	(−16.94, −3.4)	−0.04	−2.9	0.003
Family history of CVD (No)	Yes	8.80	3.31	(2.32, 15.29)	0.03	2.7	0.008
Hyperlipidaemia (No)	Yes	6.85	3.19	(0.6, 13.1)	0.03	2.2	0.032
Confirmed joining date (No)	Yes	−12.07	3.53	(−19, −5.14)	−0.04	−3.4	<0.001
CR delivery mode (Supervised delivery)	Self-delivered	−15.08	3.76	(−22.45, −7.71)	−0.05	−4.0	<0.001
Referring health professional (Consultant/cardiac nurse)	Other	20.34	5.15	(10.25, 30.44)	0.05	4.0	<0.001

* Significant if p-value < 0.05.

CR: cardiac rehabilitation. WT: waiting time. 6MWT: 6 minutes walking test. CVD: cardiovascular disease.

The significant independent variables are reported in Table 5.18. The distance walked by a patient during 6MWT post-CR would be increased by 0.82 (B = 0.81, t (1,635) = 56.5, p-value <0.05) for every increase of a meter of 6MWT pre-CR. Patients in the > 6 weeks WT group had their 6MWT post-CR measurements reduced by 9.92 m (B = −9.91, t (1,635) = −3.4, p-value <0.05) compared to the ≤ 6 weeks WT group. Examining the 3 groups of age, there was a negative relationship with 6MWT post-CR, whereas the patients became older, their performance in the 6MWT post-CR decreased by 8.79 m for 61-67 years old, by 12.82 m for 68-73 years old, and by 29.18 m for 74-100 years old. Female patients had walked less at the 6MWT post-CR compared to the male patients by 8.25 m (B = −8.25, t (1,635) = −2.4, p-value <0.05). While having diabetes mellitus was associated with a decrease of 6MWT post-CR by 10.17 m, being diagnosed with a family history of CVD or hyperlipidaemia was associated with increased it by 8.80 m and 6.85 m, respectively. Having a confirmed joining date was found to be associated with a decrease of 6MWT post-CR by 12.07 m (B = −12.07, t (1,635) = −3.4, p-value <0.05). Patients who had CR Self-delivered had performed 6MWT post-CR by less by 15.08 m (B = −15.08, t (1,635) = −4.0, p-value <0.05) compared to had supervised delivery. There was a decrease in 6MWT post-CR by 20.34 m (B = −20.34, t (1,635) = 4.0, p-value <0.05) for patients referred to CR by "other" compared to referred by consultant/cardiac nurse.

5.5.4.1.3 Factors Associated With ISWT

Multiple linear regression was conducted to examine the relationship between ISWT post-CR and several independent factors. The number of cases (n = 2,888), the result of analysis of variance was F (35, 2,852) = 280.839, p-value < 0.001 and R^2 =0.775, which means that the model could explain 78.0% of the variance in the ISWT post-CR. The assumptions of the linear regression model were examined, and none were violated.

Table 5.19 Linear Regression Results for ISWT Post-CR

Factors (reference)		Unstandardised Coefficients		95% CI	Standardised Coefficients	t-test	p-value *
		B	Std. Error		Beta		
ISWT pre-CR (continues) (m)		0.90	0.01	(0.88, 0.93)	0.76	71.0	<0.001
Waiting time (≤ 6 weeks WT)	> 6 weeks WT	−14.54	3.65	(−21.7, −7.39)	−0.04	−4.0	<0.001
Age (18-60 years old)	61-67 years old	−24.63	4.80	(−34.04, −15.22)	−0.06	−5.1	<0.001
	68-73 years old	−49.85	4.94	(−59.54, −40.16)	−0.12	−10.1	<0.001
	74-100 years old	−74.46	5.32	(−84.89, −64.04)	−0.17	−14.0	<0.001
Gender (Male)	Female	−35	4.47	(−43.77, −26.23)	−0.08	−7.8	<0.001
SES (First quintile most deprived)	Third quintile	13.71	6.03	(1.89, 25.52)	0.03	2.3	0.023
	Fifth quintile	14.75	5.90	(3.18, 26.32)	0.03	2.5	0.012
Hospital length of stay (≤ 6 days) ***	≥ 17 days	−15.28	4.56	(−24.22, −6.33)	−0.04	−3.3	<0.001
Diabetes mellitus (No)	Yes	−23.40	4.44	(−32.1, −14.7)	−0.05	−5.3	<0.001
Hypertension (No)	Yes	−8.93	3.87	(−16.53, −1.33)	−0.02	−2.3	0.021
Anxiety (No)	Yes	24.39	8.29	(8.13, 40.64)	0.03	2.9	0.003
Hyperlipidaemia (No)	Yes	9.53	3.96	(1.76, 17.3)	0.02	2.4	0.016
Confirmed joining date (No)	Yes	11.07	5.19	(1.88, 21.25)	0.02	2.1	0.033
CR delivery mode (Supervised delivery)	Self-delivered	−11.20	5.21	(−21.42, −0.98)	−0.02	−2.1	0.032
BACPR certified programme (No)	Yes	36.35	4.08	(28.36, 44.35)	0.09	8.9	<0.001

* Significant if p-value < 0.05.

**Second quintile and fourth quintile: not significant

*** Hospital length of stay 7-9 days and 10-16 days: not significant

CR: cardiac rehabilitation. ISWT: incremental shuttle-walk test. m: meter. WT: waiting time. SES: socioeconomic status. BACPR: British Association for Cardiovascular Prevention and Rehabilitation.

The summary of the significant independent variables is reported in Table 5.19. The distance walked by a patient during ISWT post-CR would be increase by 0.90 (B = 0.90, t (2,888) = 71.0, p-value < 0.05) for every increase of a meter of ISWT pre-CR. Patients in the> 6 weeks WT group had their ISWT post-CR measurements reduced by 14.54 m (B = −14.54, t (2,888) = −4.0, p-value < 0.05) compared to the ≤ 6 weeks WT group. Examining the 3 groups of age, there was a negative relationship with ISWT post-CR, whereas the patients became older, their performance in the ISWT post-CR decreased by 24.63 m for 61-67 years old, by 49.85 m for 68-73 years old, and by 74.46 m for 74-100 years old. Female patients had walked less at the ISWT post-CR compared to the male patients by 35 m (B = −35, t (2,888) = −7.8, p-value < 0.05). The second quintile and fourth quintile categories of SES were nonsignificant, but the third quintile and fifth quintile were found to be significant. There was a positive relationship between SES and ISWT post-CR; patients in the third quintile and fifth quintile were likely to perform ISWT post-CR better by 13.71 m and by 14.75 m, correspondingly. A prolonged period of hospitalisation of ≥ 17 days negatively affected ISWT post-CR performance by 15.28 m (B = −15. 28, t (2,888) = −3.3, p-value < 0.05). Having diabetes mellitus or hypertension was associated with a decrease in ISWT post-CR by −23.40 m and −8.93 m, respectively. However, patients diagnosed with anxiety had an increase of ISWT post-CR by 24.39 m (B = 24.39, t (2,888) = 2.9, p-value < 0.05). Similarly, being diagnosed with hyperlipidaemia had an increase of ISWT post-CR by 9.53 m (B = 9.53, t (2,888) = 2.4, p-value < 0.05). Having confirmed joining date was found to be associated with increasing ISWT post-CR by 11.07 m (B = 11.07, t (2,888) = 2.1, p-value < 0.05). Compared to patients who had supervised delivery, patients who had CR self-delivered had performed ISWT post-CR by less by 11.20 m (B = −11.20, t (2,888) = −2.1, p-value < 0.05). Patients who participated in CR programmes certified by BACPR had a higher ISWT post-CR performance by 36.35 m (B = 36.35, t (2,888) = 8.9, p-value < 0.05).

5.6 Discussion

This study aimed to investigate the association between waiting time for CR and patient factors, cardiac-event factors, and CR delivery factors with regularly measured CR outcomes, i.e., cardiovascular risk factors, psychological health factors and physical fitness. The analysis showed that patients who had > 6 weeks waiting time were less likely to be physically active, not depressed, or to be physical fitness.

This section will initially discuss the results in respect of each of the CR outcomes, followed by a summary of the significant findings.

5.6.1 Cardiovascular Risk Factors Outcomes

5.6.1.1 Obesity

The regression model accounted for patients' pre-CR measurements for obesity, and this method was carried forward subsequently for all other outcomes. According to this study analysis, waiting time did not influence the likelihood of patients being obese post-CR, evidenced by the higher percentages of people with obesity pre-CR as they continued being obese upon completing CR in both waiting time groups. However, the study by Marzolini et al. (2015), a Canadian-based observational study, reported an association between waiting times, calculated from the surgery date to referral receiving/CR starting, with obesity. This conflicting finding between the 2 studies could be due to 3 differences. Firstly, although both studies were retrospective analyses of post-cardiac surgeries, in this thesis, the data period was more recent (2013-2018); secondly, there were 32,109 patients with recoded obesity status, and thirdly, the obesity variable was adjusted to consider diagnostic cut-point for Asian ethnicity. In the other paper (Marzolini et al., 2015), the data were older (1995-2012), the study population was only 6,497 cases, and there was no statistical accounting for different ethnicities, which was reported to influence the

likelihood of obesity (Eastwood et al., 2015; National Institute for Health and Care Excellence, 2013).

In this analysis, older patient groups were more likely to have normal BMI post-CR compared to the younger age group (18-60 years) by 1.68 times (95% CI: 1.36, 2.07) for (68-73 years) and by 2.18 times (95% CI: 1.76, 2.68) for (74-100 years). In another observational study, Mariscalco et al. (2017) found when analysing the data for 401,227 patients post-cardiac surgery from the UK and Ireland that younger patients tended to be more obese pre-operatively. The median age for the previously mentioned study was 67 years, which is comparable to our population of 68 years. They compared age with 6 categories of BMI which span from underweight (BMI <18.5 kg/m^2) to obese class III (BMI ≥40 kg/m^2). They calculated that the median age was 69 years for normal BMI, while as the severity of obesity increased, the median age would decrease, i.e., obese class I = 66 years, obese class II = 64 years, and obese class III = 62 years. In contrast to this research's findings in post-sternotomy, a study of patients with post-PCI in the UK, al Quait and Doherty (2016) compared the change of BMI between 203,012 young patients (18 to 65 years) and 262,813 elderly patients (65 and older) and found that elderly patients had 30.0% higher likelihood of BMI improvement.

5.6.1.2 Smoking

Most of this research cohort were non-smokers at pre-CR assessment by 97.5% (34,134 cases), which improved by half a percentage to 98.0% (34,304 cases) post-CR. Also, among patients who were smokers pre-CR and quit after, 62.0% started CR early compared to 38.0% that started CR late. Moreover, it was found that of the non-smokers, 57.0% did not wait > 6 weeks to start CR, as opposed to 43.0% who waited for more. According to the regression analysis, the patient's smoking status post-CR had a nonsignificant relationship with waiting times, contrary to the finding of (Marzolini et al., 2015), who found an association between more prolonged waiting times and smoking.

The likely reason for the different findings is that, as was the case of obesity, their data was older (pre-2000), and they had fewer cases. Moreover, 2.1% of 6,497 of their population were smokers pre-CR and no mention of the number of improved cases.

Compared to not partnered patients, partnered patients were more likely to stop smoking post-CR by 44.0% (OR = 1.44, 95% CI: 1.05, 1.96). When investigating the factors associated with smoking cessation for all patients participating in CR and analysing 130,961 from the NACR database, (Salman and Doherty, 2020) reported similar findings with single patients 40.0% less likely to quit smoking post-CR. This study population included cardiac patients post medical and surgical interventions, indicating similar trends across multiple CR patient groups. A longitudinal analysis (Chandola, Head and Bartley, 2004) that involved 10,264 adults from the UK found that non-partnered smokers were less likely to stop smoking. They attributed that to insufficient social support compared to smokers with a partner.

Another factor associated with smoking post-CR is the comorbidity of depression. The chance of being a non-smoker post-CR is diminished when the patients have depression by OR = 0.48 (95% CI: 0.28, 0.81). A systematic review and meta-analysis by (Hitsman et al., 2013) examined 42 studies, assessed the connection between depression and quitting smoking, and concluded that depressed individuals were less likely to quit smoking. Also, Salman and Doherty (2020) reported that people with a high score on the HADS-Depression scale had a lower probability of stopping smoking by 5%. During a literature review that explored the current views and evidence that link smoking to depression, they reported the hypothesis that patients with depression use smoking as a means of coping and self-medication to relieve the symptoms of depression (Morozova, Rabin and George, 2015).

While this study has found that self-delivered CR was negatively associated with non-smoking post-CR, the finding of Harrison and Doherty (2018) stated that both modes of

CR delivery were equivalent in their effect on quitting smoking. The difference in results between the previously mentioned study and this study might be because of the different populations as in (Harrison and Doherty, 2018); the cohort was the whole cardiac rehabilitation population, excluding heart failure, while this study cohort was only patients post cardiac surgery. In addition to CR delivery mode, patients referred to CR by GP/primary care nurse were likelier to be non-smokers post-CR; to date, no research was identified through a literature search that attempted such comparison or reached the same result.

5.6.1.3 Physical Activity (150 min/week)

The patient's level of physical activity (150 min/week) post-CR was significantly associated with the waiting time to start CR. Patients who started CR late and had a long waiting time (> 6 weeks) were less likely to be physically active post-CR by 15.0%. This was in accordance with the reported findings of (Fell, Dale and Doherty, 2016), who evaluated the association between waiting time and physical fitness outcomes and found that patients' probability of being physically active decreased by 2% per week of waiting time.

Elderly patients aged 74-100 years had a lower possibility of being physically active post-CR by 0.83 times (95% CI: 0.72, 0.94) compared to 18-60 years. In addition to their cardiac conditions, older patients could also suffer from physical frailty (activity intolerance, muscle weakness, and atrophy), which could hinder physical activity improvement (Vigorito et al., 2017; Flint, Stevens-Lapsley and Forman, 2020). Also, being females, compared to males, had lower chances of being physically active post-CR by 19.0%.

5.6.1.4 Blood Pressure

In this study population, most patients, who were hypertensive pre-CR (78.0%), remained symptomatic with a BP ≥140/90 mmHg (≥130/80 mmHg for Asian ethnicity) upon completion of CR. Also, this study did not find a significant association between waiting times and blood pressure post-CR. This is in opposition to (Marzolini et al. 2015) findings as they reported that patients with longer waiting times had a better chance of diastolic blood pressure reduction, which could be due to having a higher diastolic blood pressure baseline, compared to patients with the shorter waiting time. Hence, the margin for improvement is more considerable.

Ethnicity had a significant association with blood pressure, whereas non-white patients had a lower probability of having normal blood pressure measurement post-CR by 58.0% compared to white patients. It was reported that non-white patients had a higher prevalence of hypertension and less blood pressure control than those in the white patient category (Schofield, Saka and Ashworth, 2011). Examining the SES role would show that patients from the third and fourth quintiles positively associated with normal blood pressure post-CR. A meta-analysis that investigated the relationship between SES and high blood pressure and included 51 studies concluded that patients with lower SES had a higher prevalence of hypertension (Leng et al., 2015).

Although patients with diabetes mellitus usually had an increased prevalence of hypertension (Sowers, 2004), in the current sample, patients with diabetes mellitus were more likely to have normal blood pressure post-CR by 21.0%. In a study of Japanese people, it was found that patients could have hypertension, diabetes mellitus and hyperlipidaemia, i.e., concurrently, having one of these conditions could lead to developing the other 2 conditions (Fukui et al., 2011). According to this study analysis, having hypertension would increase the likelihood of having normal blood pressure post-

CR, while having hyperlipidaemia would decrease the likelihood of having normal blood pressure post-CR.

5.6.2 Psychological Health Factors Outcomes

5.6.2.1 HADS-Anxiety

There was a nonsignificant association between HADS-Anxiety post-CR and waiting time, in contrast to (Sumner, Böhnke and Doherty, 2018). They analysed the data from 39,588 cardiac patients who received a medical or surgical intervention and then completed CR from 2012 to 2016, and they found that long waiting time was associated with abnormal HADS-Anxiety levels post-CR. According to the analysis, patients who were 61 years or older were more likely to complete CR with normal HADS-Anxiety scores than 18 to 60 years old patients. There was further research that has explored the connection between anxiety and age among healthy adults and patients pre-CR and found that younger patients tend to have a higher level of anxiety compared to older people (Gerolimatos and Edelstein, 2012; Mahoney, Segal and Coolidge, 2015; O'Neill et al., 2021). Female patients were less likely to have normal anxiety levels post-CR than males by 29.0%. In general, as with younger age, the prevalence of anxiety among women was higher than in men (Kessler et al., 2005).

5.6.2.2 HADS-Depression

HADS-Depression post-CR had a significant association with waiting time. Patients who waited for > 6 weeks to start CR were less likely to be in the normal category by 19.0% on the HADS-Depression scale upon completing CR. This aligns with the finding of (Sumner, Böhnke and Doherty, 2018), as they linked abnormal HADS-Depression scores with waiting a long time. In addition, the results seem to link patients' age and depression, as patients from 61 years and older were more likely to be non-depressed post-CR than patients aged 18 to 60 years old. Both (Mallik et al., 2005; Mikkelsen et al., 2019) reported

a higher prevalence of depression among young patients than in older patients. In the current study, partnered patients had a lower probability of being not depressed after completing CR by 18.0% times than non-partnered.

On the other hand, (Yan et al., 2011) ran a meta-analysis that included 32 observational studies (8 longitudinal and 24 cross-sectional) to explore partnership status and depression. They found that participants from the public aged 55 years and older who were unpartnered had a higher risk of depression compared to those partnered. Similar to anxiety, patients from less deprived quintiles were found to be more likely to be normal on the HADS scale for depression than patients from the most deprived areas. (Sever et al., 2019) also found a connection between lower SES and being diagnosed with depression pre-CR for the first time.

5.6.2.3 Feelings (Dartmouth)

Analysis showed no association between patients' feelings (Dartmouth) post-CR and waiting time. Patients aged 61 years and older were more likely to report healthier feelings (Dartmouth) post-CR than younger patients. Meanwhile, female patients were less likely to report healthier feelings (Dartmouth) by 20.0% post-CR. In 2003, Turner et al. (2003) analysed the data for 1,403 CR patients in the UK and found a significant improvement in the feeling domain of the Dartmouth Coop questionnaire. However, they found that age (62 ±9.97 years) and gender (78.0% male) were not factors in predicting changes in their sample (Turner et al., 2003).

5.6.2.4 QOL (Dartmouth)

The regression analysis showed no association between waiting time and QOL (Dartmouth) after completing CR. There was a positive relationship between healthy QOL (Dartmouth), and patients aged 61 to 73 years old. Being diagnosed with diabetes mellitus decreases the patient's probability of having healthy QOL (Dartmouth)

outcomes. Wald and Crecelius, (2016), conducted a study to examine the effect of CR in improving QOL in patients with and without diabetes. It was an observational US-based study with 37 patients in the diabetic group and 58 patients in the non-diabetic, and they reported that both groups had significant improvement in QOL, but neither age nor diabetes was predictive of that change. Patients with anxiety or depression had lower chances of healthy QOL post-CR by 56.0% and 63.0%, respectively. A study aimed to assess the prolonged effect of CR on 147 patients and found that depression at the 12-month follow-up negatively affects patients' QOL (Yohannes et al., 2010).

5.6.3 Physical Fitness Factors Outcomes

5.6.3.1 Physical Fitness (Dartmouth)

Waiting > 6 weeks to start CR would decrease patients' chance of being subjectively physically fit by 23.0% compared to patients who waited for less time. In Fell, Dale and Doherty (2016) study, they also found a 23.0% drop in the probability of physical fitness (Dartmouth) for patients who started CR late. Age was a significant factor in negatively influencing patients' likelihood of having healthy physical fitness post-CR for patients from 68 and older. Also, the female gender was less likely to report being healthy on the physical fitness scale by 48.0% than male patients. In a study where they compared 156 older patients ($\geq$ 65 years) and 144 younger patients (< 65 years) in terms of improvement of physical fitness (Dartmouth) post-CR, they all experienced improvement with a nonsignificant between them (Kardis, Sherman and Barnett, 2007). However, they also found that men were significantly higher in the physical fitness component when compared to women. A UK retrospective study examined physical fitness (Dartmouth) results for 1,077 CR patients and found that older patients had less improvement, age was a predictor for the change, and gender was not a predictor (Turner et al., 2003). Non-white patients had less probability of healthy physical fitness than white patients by

41.0%. Compared to the patients with the lowest SES, the higher their SES, the higher patient's likelihood of completing CR with healthy physical fitness. Hospitalisation for more than 10 days would lower patients' odds of being healthy at the physical fitness component post-CR. Diabetes is associated with decreased healthy physical fitness in this study cohort, unlike the finding of Wald and Crecelius (2016) study. The comorbidity of depression and the self-delivery mode was linked to a lower physical fitness outcome.

5.6.3.2 6MWT Post-CR

This study found a significant association between the 6MWT post-CR measurements and waiting time. Patients who waited > 6 weeks to start CR had finished 6MWT post-CR by 10 m less than earlier CR starters. While patients in the 2 waiting groups were able to achieve the MCID for 6MWT, which is > 25 m, the patient who started early CR had a significantly higher difference of 73 m compared to 68 m for patients who started late (Gremeaux et al., 2011). In Macchi et al. (2007) study, they compared the 6MWT performances of 300 post-cardiac surgeries as they were divided between an early CR group (started during the second-week post-op) and a late CR group (started during the fourth-week post-op) and found the early group had performed significantly better than the late group. In a more recent Australian-based observational study, Candelaria et al. (2021) analysed the data for 849 CR patients to evaluate the effect of waiting time and patient-related factors on improving 6MWT walking distance. Factoring waiting time as a continuous variable, they found that for every increase of waiting time by a day, there was a decrease in 6MWT walking distance by 0.2 m. A systematic review and meta-analysis aimed to compare the 6MWT performances between 2 groups that started CR early (within 2 weeks post-op) with those who started later; they found only 7 studies that fit the criteria (Doyle et al., 2019). However, they could not calculate the pooling mean for the meta-analysis due to the considerable heterogeneity in the studies.

In the current study, age was a negative factor for patients aged 61 years and older compared to patients 18-60 years old, i.e., as the patients move to the older age group from 18-60, their walking distance would decrease, and their performance would be less. Also Macchi et al. (2007) found that when comparing patients aged <75 years with ≥ 75 years old, age was not a significant factor in the 6MWT improvement between the early and late CR groups. Regarding patients' gender, the analysis in the current study revealed that women patients would walk less than men patients by 8 m during 6MWT after completing CR. In an observational study by Feola et al. (2015), they compared the performance of both gender of CR patients; 295 males and 123 females. The male patients were younger, 67.9, SD = 10.2 years (female 70.5, SD = 9.2 years), and the 6MWT walking distance for male patients pre-CR was higher than their counterpart, as well as the 6MWT walking distance post-CR. In Switzerland, Bierbauer et al. (2020) conducted a study to examine the factors that could predict 6MWT performance for 13,612 CR patients. They reported that being male and younger were significant predictors for better 6MWT measurements post-CR. Candelaria et al. (2021) found that as patients age, their 6MWT walking distance decreases; also, being women would mean less improvement in walking distance compared to men. In this study cohort, patients with diabetes mellitus covered more walking distance, which differs from the finding of other research that counted being diagnosed with diabetes mellitus as a factor in decreasing the performance of 6MWT (Fiorina et al., 2007; Bierbauer et al., 2020; Candelaria et al., 2021). Patients who had self-delivered CR walked 15 m less than patients who had supervised delivery, which was in opposition to the reported conclusion by Harrison, Tang and Doherty (2018), as they found a nonsignificant association between CR mode of delivery and 6MWT performance.

5.6.3.3 ISWT Post-CR

CR was shown to increase the level of physical fitness of the patients in all waiting groups as it was reflective of acceding the MCID for ISWT, which is 70 m (Houchen-Wolloff, Boyce and Singh, 2015). There was a significant association between waiting time and ISWT performance, where the patients who waited > 6 weeks to start CR would walk 14 m less than patients who started earlier. It is important to remember that patients who waited longer had less walking distance pre-CR and post-CR than patients in the ≤ 6 weeks WT group. In an NACR database study, they analysed the data for 32,899 CR patients from 2012-2015 to investigate the association between ISWT and waiting time in 2 forms, continuous and categorical and found that longer waiting time was significant in decreased ISWT outcome post-CR (Fell, Dale and Doherty, 2016).

In this study, age was a significant factor as the analysis showed that as the patient got older, their ISWT walking distance decreased. In a single centre-based retrospective study, McKee et al. (2013) analysed the data for 154 CR patients and found that age was negatively associated with ISWT distance, i.e., younger patients would walk longer than older patients. A similar finding was reported by a more extensive scale NACR retrospective study by al Quait and Doherty (2016), as patients 18-65 years old had a 70.0% chance of better ISWT performance than patients older than 65 years old. In addition, female patients were connected to less ISWT walking distance and lower physical fitness than male patients.

In another NACR retrospective study by (Alotaibi and Doherty, 2017), they aimed to find the factors that influence ISWT performance by analysing the data collected from 2010-2015 of 8,863 CR patients, and they found gender, specifically male gender, to be a predictor of better ISWT compared to female patients. While they did not find diabetes mellitus, hypertension, and hyperlipidaemia to be significant variables, they were significant in this study. Patients diagnosed with diabetes mellitus or hypertension were

negatively associated with ISWT and walked less distance, unlike patients with hyperlipidaemia, who would cover more walking distance during the physical fitness test. In addition, patients who had self-delivered CR walked 11 m less than patients who had supervised delivery, whereas Harrison, Tang and Doherty (2018) found that the mode of CR delivery did not influence ISWT performance.

According to the results, waiting time had a minimal association with a favourable outcome of the cardiovascular risk factors post-CR, except with physical activity (150 min/week). Also, waiting time had a nonsignificant association with a favourable outcome of the psychological health factors post-CR, except HADS-Depression. Meanwhile, waiting time had a significant association with all physical fitness outcomes. Therefore, the research failed to reject the null hypotheses regarding obesity, smoking, blood pressure, HADS-Anxiety, HADS-Depression, feelings (Dartmouth), and QOL (Dartmouth), and rejected the null hypotheses and accept the experimental hypotheses for (physical activity-(150 min/week)), physical fitness (Dartmouth), 6MWT, and ISWT. Table 5.20 summarises the relationships between the outcomes and the independent variables.

Table 5.20 Summary of the Significant Independent Variables and its Positive (+ve) or Negative Association (-ve) for all Chapter 5 Outcomes

Dependent Variables * / Independent Variables**	Obesity	Smoking	Physical activity (150 min/week)	Blood pressure	HADS-Anxiety	HADS-Depression	Feel (Dartmouth)	QOL (Dartmouth)	Physical fitness (Dartmouth)	6MWT	ISWT
Waiting time			−ve			−ve			−ve	−ve	−ve
Age	+ve		−ve	+ve	+ve	+ve	+ve	+ve	−ve	−ve	−ve
Gender			−ve		−ve		−ve		−ve	−ve	−ve
Ethnicity	+ve			−ve	−ve	−ve			−ve		
Partnership status		+ve				−ve	−ve				
SES	+ve		+ve	+ve	+ve	+ve			+ve		+ve
Previous CR					−ve		−ve				−ve
Treatment type				+ve							
Hospital length of stay			−ve	−ve		−ve			−ve		
Angina										+ve	−ve
Diabetes mellitus	−ve		−ve	+ve				−ve	−ve		−ve
Hypertension			+ve	+ve			−ve				+ve
Anxiety				−ve	−ve	−ve	−ve	−ve			
Depression		−ve			−ve	−ve	−ve	−ve		−ve	−ve
Family history of CVD			+ve							+ve	+ve
Hyperlipidaemia	−ve		+ve	−ve							
Number of comorbidities			−ve	−ve						+ve	+ve
Confirmed joining date			−ve							−ve	
Referring health professional		+ve	−ve			−ve				−ve	−ve
CR delivery mode		−ve							−ve		
Multidisciplinary team			−ve					+ve			+ve
BACPR certified programme				+ve							+ve

* For more details about the coding of the variables, see Table 5.1. ** For more details about the coding of the variable, see Table 3.1 and Table 4.1 and for which one of the categories was significant, see the regression analysis table for the corresponding outcome. +ve: Indicate a positive association. −ve: Indicate a negative association

CVD: cardiovascular disease. AMI: Acute myocardial infarction. CABG: coronary artery bypass grafting. CR: cardiac rehabilitation. CVD: cardiovascular disease. BMI: body mass index. HADS: Hospital Anxiety and Depression Scale. BACPR: British Association for Cardiovascular Prevention and Rehabilitation. SES: socioeconomic status.

5.7 Conclusion

A long waiting time of > 6 weeks was associated with decreasing the probabilities of positive outcomes for all the physical fitness and activity outcomes (subjective and objectively measured) and failing to modify the risk factor of depression upon completing CR. In addition to depression, the study revealed a clear connection between waiting time to start CR and all the physical aspects of the patient's well-being and recovery post-sternotomy. Prolonged waiting time leads to unfavourable outcomes and undermines cardiac rehabilitation's primary purpose, which presses to optimise patient health in its different forms. Being female or diagnosed with depression appeared to be the 2 highest independent factors negatively correlated with 6 out of 11 CR outcomes. On the other hand, being from higher SES and ageing was associated with positive results for 6 and 7 CR outcomes, respectively.

5.8 Strengths and Limitations

The study's findings were drawn from an up-to-date large sample using the NACR database that captures routine practice data, which gives the advantage of having a generalisable and actual illustration of the population. Another strength of this study is analysing 3 essential CR categories that include 11 outcomes, i.e., cardiovascular risk factors, psychological health factors, and physical fitness factors. Moreover, there was an adjustment for obesity and blood pressure to reflect the diagnostic cut-point for the Asian ethnicity. On the other hand, the observational study comes with certain limitations: the probability of missing data that can limit the use of independent variables or the number of cases during analysis.

CHAPTER 6 Synthesis

6.1 Introduction

This chapter aims to synthesise the results from chapters 3 (starting CR), 4 (completing CR) and chapter 5 (CR outcomes), i.e., chapters 3, 4, and 5, respectively. This thesis aimed to determine the extent to which there is an association between waiting time and CR starting, completion and outcomes for patients post-CABG, post-valve surgeries, and combined CABG and valve surgeries. The analyses of NACR data showed that waiting time had a significant association with patients' probability of starting, completing and outcomes of CR. Furthermore, the prolonged waiting time showed a mitigated utilisation and benefits from CR programmes for patients after median sternotomy surgeries.

Mixed Directions of Association
Age** (Older)
Ethnicity (Non-white)
Partnership status (Partnered)
Diabetes mellitus (Yes)
Hypertension (Yes)
Anxiety (Yes)
Hyperlipidaemia (Yes)
Confirmed joining date (Yes)
Referring health professional*

Positive Direction of Association
SES* (Higher quintiles)

Negative Direction of Association
Gender (Female)
Hospital length of stay* (Longer length of stay)
Depression (Yes)
Number of comorbidities* (Higher number of comorbidities)
CR delivery mode (Self-delivered)

Factors included in the synthesis are classified based on the direction of the association with CR starting, completing and outcomes.

Figure 6.1 Significant Factors and Their Directions of Association with CR Starting, Completing and Outcomes

* A multicategorical variable. ** A continuous variable in chapters 3-4 and a multicategorical variable in chapter 5. SES: socioeconomic status.

In addition, there was an investigation for the association of patients, cardiac-event, pre-CR assessment, CR delivery with CR utilisation and outcomes. The independent factors incorporated in this synthesis were included in at least 2 studies. The included variables

were classified according to being modifiable (can be controlled) and non-modifiable. They would be further categorised based on their direction of the association, positive, negative, and mixed positive and negative (see Figure 6.1). The inclusion criteria for its synthesis chapter were any factors that illustrated the same association direction with 3 minimum significant findings or factors with mixed associations with 4 minimum significant associations.

6.1.1 Waiting Time

The investigation into how waiting time was associated with CR participation was examined via the influence on starting and completing CR as well as CR outcomes. It was revealed that a prolonged waiting time of more than 6 weeks increased the patients' chances of starting CR by 2.55 times (95% CI: 2.41, 2.70). A potential reason for the delayed CR starting could be due to clinicians striving to follow the CR guidelines recommendation of 6 to 8 weeks waiting time (Piepoli et al., 2010; Royal Dutch Society for Physical Therapy, 2011; Environment et al., 2014). However, once the patient has commenced core rehabilitation, the results from chapters 4 and 5 showed that shorter waiting time had a neutral association or a positive significant association with CR completion or improved outcomes. Prolonged waiting time decreases patients' chances of completing CR by 6% (OR: 0.94, 95% CI: 0.89, 0.99). Also, prolonged waiting time decreases the probability of being physically active, not depressed, and physical fitness on both subjective and objective measurements. This finding is mirrored in other research; see chapters 3 and 4 for individual breakdown. These results allow a clear line linking prolonged waiting time with an increased likelihood of adverse CR outcomes for patients post-sternotomy. It also allows for a solid recommendation for less than 6 weeks of waiting time for patients to start CR, considering the results from the large multicentre population. Annual reports from NACR show that decreasing the waiting time for CABG patients can be accomplished as there was a reduction from 46 days in the 2016 report to

33 days in 2020 (NACR, 2016; British Heart Foundation, 2020). Therefore, by advocating for a shorter waiting time and an early start of CR, patients would avoid the consequence of starting late by increasing the CR completion rate and outcomes to achieve CR's optimal goals for better health and life. In addition to the benefits at a patient level, shorter waiting time aligns with BACPR standards for CR programme certification requirements (BACPR, 2017).

This thesis did not investigate the safety of ≤ 6 weeks WT versus > 6 weeks WT, as the NACR does not collect the reported adverse events that may occur during CR duration. It would be beneficial if NACR could consider collecting such information as it will aid in researching this aspect of early CR. However, it was already addressed in earlier research, as in a systematic review by Doyle et al. (2019), where they investigated the safety and efficacy of aerobic exercise started early for patients post-CABG or post-valve surgeries. There were 6 studies that reported that adverse events occurred following aerobic exercise in both the intervention and the usual groups. A meta-analysis was conducted for the 6 studies, and the result showed a nonsignificant difference in the adverse events between the intervention groups and the usual group OR: 0.41, (95% CI: 0.12–1.42, p-value = 0.16).

6.1.2 Non-Modifiable Independent Factors

Across the analyses presented in Chapters 3-5, there were a group of non-modifiable independent variables with various directions of association. The analyses in all 3 studies included 6 non-modifiable patient factors, i.e., age, gender, ethnicity, partnership status, SES, and history of previous CR.

6.1.2.1 Factors With Consistent Negative Direction of Association

Gender was significantly associated with starting and completing CR and 6 CR outcomes, while there was a nonsignificant association with the remaining outcomes. Being female

is associated with a lower likelihood of starting and completing CR than male patients. Moreover, being female had a lower probability of completing CR with regular physical activity (150 min/week), healthy anxiety levels and normal feelings (Dartmouth) scores, and all physical fitness measures. Therefore, recruiting more female patients and redesigning rehabilitation is paramount, which was emphasised by NACR 2019 recommendations (British Heart Foundation, 2019b).

6.1.2.2 Factors With Consistent Positive Direction of Association

When significant, higher SES levels appeared to have a positive association and increased chances to start and complete CR. Additionally, patients with higher SES levels had higher odds of not being obese, regular physical activity (150 min/week), normal blood pressure, healthy scores for HADS-Anxiety and HADS-Depression, and physical fitness (Dartmouth) and ISWT post-CR. This means patients from lower SES were experiencing immense difficulties that led to underutilising and underperforming during rehabilitation programmes.

6.1.2.3 Factors With Mixed Directions of Association

Age was an important factor as it had significant associations with all the outcomes in the thesis, except for smoking. Older age showed negative associations with starting CR and all 4 physical measurements, i.e., practising regular physical activity (150 min/week), physical fitness (Dartmouth), 6MWT and ISWT. However, there were positive associations between older age with completing CR, not being obese, normal blood pressure, healthy scores for HADS-Anxiety and HADS-Depression, and normal feelings (Dartmouth) and QOL (Dartmouth). In terms of patients' participation, e.g., starting and completing, the mixed association has led to a critical action within CR services because once older patients are successfully recruited, they are more likely to complete the programme.

Non-white ethnicity patients had increased odds of starting CR and not being obese post-CR compared to white patients. However, they had decreased odds of normal blood pressure, healthy scores for HADS-Anxiety and HADS-Depression, and physical fitness (Dartmouth) upon completing CR. Although the CR programmes in the UK successfully recruited patients from ethnic minorities, based on the association of some, the CR outcomes highlight the need to review programmes for reasons of lower results.

Partnership status was a significant independent variable for starting and completing CR, as partnered patients had a better likelihood than their non-partnered counterparts. In addition, partnered patients had better chances of being non-smokers post-CR while lower chances for healthy HADS-Depression and normal feelings (Dartmouth) levels.

6.1.3 Modifiable Independent Factors

6.1.3.1 Factors With Consistent Negative Direction of Association

Hospital length of stay, depression, mode of delivery and number of comorbidities consistently exhibited negative associations across the thesis outcomes. According to the analyses from the first and second studies, prolonged hospital length of stay decreases the patients' chances of starting and completing CR. Furthermore, there was an associated reduction in the patient's chances of being physically active, not having hypertension, not being depressed, reporting healthy physical fitness (Dartmouth), and reducing ISWT performance. As hospital length of stay has been documented to be associated with an increased risk of hospital readmission (Hannan et al., 2003, 2011; Shah et al., 2019), it appears that its adverse effect extends beyond readmission to influence the CR intervention pathway and outcomes negatively. This finding is very important to inform clinical practice to keep the hospital length of stay as short as is clinically permissible.

The body of evidence presented above shows a consistent finding that patients' comorbidity status of depression has a negative association with completing the programme, quitting smoking, healthy physical fitness (Dartmouth), and all the

psychological health factors. In addition, based on the literature, it is acknowledged that the burden of depression on an individual as it increases 2-fold the likelihood of being a smoker upon completion of CR (Weinberger et al., 2017), increases the probability of anxiety and having recorded lower QOL (Hare et al., 2014), in addition to decreasing their physical activity levels (Schuch et al., 2017). Consequently, it is imperative for clinicians to counterbalance the impact of depression on patients during CR by increasing the support and resources available for them.

This thesis examined the association of CR mode of delivery from the point of starting CR until the point of completion and the results of post-CR assessments. The mode of delivery was found to have a significant relationship with completing the rehabilitation programme, being non-smoking, and all physical fitness factors. This study adds to the literature and informs professionals in charge of CR delivery that patients in self-delivery modes are less likely, compared to supervised modes, to complete the programme, be non-smokers, had healthy physical fitness (Dartmouth), and perform less in 6MWT and ISWT. Thus, there may be a need to review the current self-delivery protocols and reinforce required modifications to improve patients' opportunity to complete the CR and benefit from it wholly.

Unlike research that analysed the PCI population (Al Quait, 2018), logistic regression in chapter 4 found a significant association between CR completion and the number of comorbidities for post-median sternotomy, with ≥ 3 comorbidities decreasing the patients' odds of completing CR. Among all the investigated CR outcomes, only 2 were significantly associated with the number of comorbidities: physical activity (150 min/week) and blood pressure. The burden of an increase in the number of comorbidities interferes with patients' chances of modifying the cardiovascular risk factors, particularly having normal physical activity and not being hypertensive.

6.1.3.2 Factors With Consistent Mixed Directions of Association

Diabetes mellitus, hyperlipidaemia, anxiety, referring health professional, hypertension, and confirmed joining date all showed a mixture of both negative and positive associations with the thesis independent factors.

Diabetes mellitus was negatively associated with CR utilisation and 5 CR outcomes while positively associated with the other 2. It is a chronic condition that could result from obesity and low physical activity, leading to low QOL (Jing et al., 2018; Carbone et al., 2019). Therefore, the burden of these interlinked conditions could explain the reduction in starting and completing CR. Moreover, the results revealed the association between diabetes mellitus and low positive CR outcomes; this could mean that the current CR programmes need to be more dynamic to tackle the consequence of diabetes mellitus. Also, the results highlight that patients with diabetes mellitus would perform differently between 6MWT and ISWT, where they would perform better than their counterparts during 6MWT but not during ISWT. This could be due to the difference between the two field walking tests, as 6MWT is self-paced while ISWT is externally paced (ATS Committee on Proficiency Standards for Clinical Pulmonary Function Laboratories, 2002; Singh et al., 1992).

In the first and second studies, patients with hyperlipidaemia appeared to have more chances to start and complete CR than patients without it. It was reported that there is a perception that hyperlipidaemia is a high-risk factor for cardiac deterioration, which influence high CR referral (Soroush et al., 2018); this could also influence patients to start and complete CR. This might also motivate them to perform better on physical activity and fitness assessments. As there is a pathophysiology link between hyperlipidaemia with obesity (Poirier et al., 2006) and hypertension (Halperin et al., 2006), the results also demonstrated a reduced chance for patients with hyperlipidaemia completing CR without

the latter conditions. Thus, further investigation is needed into the possible CR modification that would result in a positive association.

The comorbidity of anxiety displayed a negative association with blood pressure and all psychological health outcomes. The results regarding anxiety were not unexpected in the view of existing publications that analysed the anxiety associated with hypertension (Pan et al., 2015), depression (Kalin, 2020), and lower QOL (Norberg, Diefenbach and Tolin, 2008). The restlessness and the urge to move, which usually characterise patients with anxiety (Bambauer et al., 2005), could explain why they outperform patients without anxiety during ISWT post-CR.

Hypertension as comorbidity at baseline had a complicated association with patient outcomes, being both a positive association or an inhibiter for change. As found in another study, patients with hypertension who received CR were more likely to complete the programme without having high blood pressure and meet the recommended level of physical activity (Piercy and Troiano, 2018). However, on the other hand, hypertension lowers the patients' chances of reporting healthy feelings (Dartmouth) and fewer distances during ISWT post-CR. This mixed association highlights the importance of baseline assessments and comorbidities identification when setting CR goals.

The independent factor of referring health professional, i.e., the professional who referred the patient to CR, was found to have a significant association with CR completion, smoking, physical activity (150 min/week), depression and 6MWT post-CR. Compared to a consultant/cardiac nurse, a referral from the category "other" increased the probability of completing CR while decreasing the probability of healthy physical activity, no depression and lower 6MWT post-CR performance. This finding highlights the variable influence that the staff who refer to CR has on the patient and subsequent outcomes. Future research may identify patient types or characteristics that benefit from receiving a referral from specific staff types. In addition, CR services may require a

review of how the data for this variable (referring health professional) is coded and collected to identify the "other".

A confirmed joining date could give an indication of the quality of CR service as it documents those patients who had received a letter informing them when they would be expected to enrol to CR. However, before this thesis, only one study investigated confirmed joining date (al Quait et al., 2017) and reported an association with increased CR engagement for patients post-PCI. For the population of this thesis, having a confirmed joining date was associated with increased CR utilisation (starting and completing) and better 6MWT and ISWT performance while decreasing the likelihood of reporting healthy physical activity. These results could be a good sign for the clinician in the importance of sending, following up and confirming that CR-eligible patients are informed about the joining date to the rehabilitation programme.

CHAPTER 7 Conclusion and Recommendations

7.1 Conclusions

This is the first thesis that has investigated, for patients post sternotomy, the association of waiting time with CR utilisation (starting and completing) and 3 categories of outcomes. Although the research studied waiting time, this thesis has used the most recent available data and focused on patients post-CABG, post-valve surgeries, and combined surgeries.

- Waiting time was a serious factor influencing CR services for patients post-cardiac surgeries.

- Despite the guidelines, patients' age, gender, and SES still play a considerable role in CR utilisation and outcomes.

- A need for specific patient demographic groups using CR that can benefit from more psychological health support.

- There are requirements for a more all-inclusive thorough approach in enrolling eligible patients with special consideration to the patient's characteristics and medical history.

Moreover, the demographics for patients recruited to the SCAR trial resulted in the mean age of participants = 63.0 years (84.0% male), and it was 65.0 years (87.0% male) for the SheppHeartCABG trial. In this PhD thesis, the mean age for UK routine practice post sternotomy patients was 66.0 years (77.0% male). In essence, this thesis is based on a larger, more inclusive and representative population. This further supports the NICE recommendation that observational studies taking account of data from real-world settings represent an important part of the evidence base.

7.2 Recommendations and Actions

Recommendations based on the results of the thesis:

- Advise both clinicians and patients of the benefit of starting CR early, i.e., waiting less than 6 weeks to avoid dropping out of the programmes and to improve the chances of its completion along with improved outcomes.

- Educate both clinicians, female patients, and patients from lower SES that their gender and SES put them at a disadvantage for starting, completing, or benefiting fully from the CR programmes. While clinicians need to tailor CR programmes to make them more accommodating to the patient's conditions, the patient needs to communicate to the clinician the obstacles they face so they would be provided with available support.

- Increase advice and psychological health support within CR programmes for patients from ethnic minorities and unpartnered patients.

- Advise CR services providers to increase the effort in recruiting older patients to CR programmes as they were more likely to complete once they started.

- Although shorter hospital length stay is widely endorsed, prolonged hospital stays may be inevitable due to patients' medical conditions. Therefore, a more extensive effort is advised in recruiting patients who had prolonged hospitalisation to increase the likelihood of their CR utilisation and receiving the appropriate intervention.

- Advice for more tailored CR programmes, i.e., customised for their needs for patients with comorbidities of diabetes mellitus, hypertension, anxiety, depression, hyperlipidaemia, or having more than 3 comorbidities.

7.3 Research Recommendations

- The factor of treatment types was found to be significant during the first study (starting CR), the second study (completing CR) and blood pressure post-CR. Further

analyses may be helpful in inspecting the potential reasons for higher chances of CR utilisation and lower chances of normal blood pressure for patients post-CABG.

- Throughout this thesis, age, gender, and SES were found to be associated with CR starting, completing, and outcomes and future research in a qualitative manner may help explore the interaction between age and gender in terms of CR starting and better understand the different participation rates for these patients' groups.

List of Abbreviations

%	percentage
6MWT	6 minutes walking test
ACS	acute coronary syndrome
AMI	acute myocardial infarction
AUC	area under the curve
BACPR	British Association for Cardiovascular Prevention and Rehabilitation
BHF	British Heart Foundation
BMI	body mass index
CABG	coronary artery bypass grafting
CAD	coronary artery disease
CHD	coronary heart disease
CI	confidence interval
CR	cardiac rehabilitation
CVD	cardiovascular disease
df	degrees of freedom
DM	diabetes mellitus
GP	general practitioner
HADS	Hospital Anxiety and Depression Scale
HRQL	Health-Related Quality of Life
ICU	intensive care unit
IMD	Index of Multiple Deprivation
ISWT	incremental shuttle-walk test
JBI	The Joanna Briggs Institute
m	meter
MeSH	medical subject headings
MI	myocardial infarction
min	minute
NACR	National Audit of Cardiac Rehabilitation
NHS	National Health Service
NICE	National Institute for Health and Care Excellence
NSTEMI	non-ST-elevation myocardial infarction
OR	odds ratio
PCI	percutaneous coronary intervention
PEDro	The Physiotherapy Evidence Database
PICO	Population, Intervention, Comparison, Outcome.
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
QOL	quality of life
RCT	randomise controlled trial
ROC	receiver operator characteristic
RR	risk ratio
SD	standard deviation
SE	standard error
SES	socioeconomic status
SF-36	the short form 36 health survey questionnaire
Sig	significant
STEMI	segment elevation myocardial infarction
UK	United Kingdom
VIF	variance inflation factors
VO_{2peak}	peak oxygen uptake
WT	waiting time

Appendices

Appendix A

The Original Search Strategies

The following are the search strategies used: the Ovid Medline (the national library of medicine's premier database), Embase (The Excerpta Medica database) and Central (The Cochrane Central Register of Controlled Trials).

Database: Ovid MEDLINE(R) ALL <1946 to April 03, 2019>
Search Strategy:
1 exp Coronary Artery Bypass/ (50816)
2 Sternotomy/ (2091)
3 Myocardial Revascularization/ (10617)
4 Cardiac Rehabilitation/ (1851)
5 cardiac rehab$.ti,ab. (5659)
6 (1 or 2 or 3) and (4 or 5) (507)
7 exp Coronary Artery Bypass/rh (852)
8 Myocardial Revascularization/rh (89)
9 coronary artery bypass graft$.ti,ab,kw. (30729)
10 Cardiac Rehabilitation/ (1851)
11 cardiac rehab$.ti,ab. (5659)
12 9 and (10 or 11) (334)
13 CABG.ti,ab. (16666)
14 Myocardial Revascularization.ti,ab. (4317)
15 Myocardial Revascularisation.ti,ab. (377)
16 Cardiac Rehabilitation/ (1851)
17 cardiac rehab$.ti,ab. (5659)
18 (13 or 14 or 15) and (16 or 17) (220)
19 6 or 7 or 8 or 12 or 18 (1305)
20 limit 19 to english language (1019)

Database: Embase <1974 to 2019 April 03>
Search Strategy:
1 exp Coronary Artery Bypass/ (68886)
2 heart muscle revascularization/ (29651)
3 Heart Rehabilitation/ (10073)
4 cardiac rehab$.ti,ab. (9574)
5 (1 or 2) and (3 or 4) (1370)
6 exp Coronary Artery Bypass/rh (315)
7 heart muscle revascularization/rh (35)
8 coronary artery bypass graft$.ti,ab. (39991)
9 myocardial revascularization.ti,ab. (5115)
10 myocardial revascularisation.ti,ab. (529)
11 Heart Rehabilitation/ (10073)
12 cardiac rehab$.ti,ab. (9574)
13 (8 or 9 or 10) and (11 or 12) (665)
14 CABG.ti,ab. (29701)
15 Heart Rehabilitation/ (10073)
16 cardiac rehab$.ti,ab. (9574)
17 14 and (15 or 16) (564)
18 5 or 6 or 7 or 13 or 17 (1936)
19 limit 18 to english language (1689)

Database: Central

ID   Search
#1   MeSH descriptor: [Coronary Artery Bypass] explode all trees
#2   MeSH descriptor: [Cardiac Rehabilitation] explode all trees
#3   ("cardiac rehab*"):ti,ab,kw (Word variations have been searched)
#4   #1 and (#2 or #3)
#5   MeSH descriptor: [Coronary Artery Bypass] explode all trees and with qualifier(s): [rehabilitation - RH]
#6   MeSH descriptor: [Myocardial Revascularization] explode all trees and with qualifier(s): [rehabilitation - RH]
#7   ("coronary artery bypass graft*"):ti,ab,kw (Word variations have been searched)
#8   ("myocardial revascularization" or "myocardial revascularisation"):ti,ab,kw (Word variations have been searched)
#9   MeSH descriptor: [Cardiac Rehabilitation] explode all trees
#10   ("cardiac rehab*"):ti,ab,kw (Word variations have been searched)
#11   (#7 or #8) and (#9 or #10)
#12   (CABG):ti,ab,kw (Word variations have been searched)
#13   MeSH descriptor: [Cardiac Rehabilitation] explode all trees
#14   ("cardiac rehab*"):ti,ab,kw (Word variations have been searched)
#15   #12 and (#13 or #14)
#16   #4 or #5 or #6 or #11 or #15

170 records identified

Appendix B

The Updated Search Strategies

Ovid MEDLINE(R) ALL
via Ovid http://ovidsp.ovid.com/
Date range searched: 1946 to April 12, 2022
Date searched: 13 April 2022
Records retrieved: 1164

1 exp Coronary Artery Bypass/ (55447)
2 Sternotomy/ (2876)
3 Myocardial Revascularization/ (11600)
4 Cardiac Rehabilitation/ (3313)
5 cardiac rehab$.ti,ab. (7413)
6 (1 or 2 or 3) and (4 or 5) (604)
7 exp Coronary Artery Bypass/rh (887)
8 Myocardial Revascularization/rh (95)
9 coronary artery bypass graft$.ti,ab,kw. (35704)
10 Cardiac Rehabilitation/ (3313)
11 cardiac rehab$.ti,ab. (7413)
12 9 and (10 or 11) (433)
13 CABG.ti,ab. (19562)
14 Myocardial Revascularization.ti,ab. (4619)
15 Myocardial Revascularisation.ti,ab. (393)
16 Cardiac Rehabilitation/ (3313)
17 cardiac rehab$.ti,ab. (7413)
18 (13 or 14 or 15) and (16 or 17) (281)
19 6 or 7 or 8 or 12 or 18 (1457)
20 limit 19 to english language (1164)

Key:
/ = indexing term (Medical Subject Heading: MeSH)
exp = exploded indexing term (MeSH)
/rh indexing term with rehabilitation subheading
$ = truncation
ti,ab,kw = terms in either title, abstract or keyword fields

Embase
via Ovid http://ovidsp.ovid.com/
Date range searched: 1974 to 2022 April 12
Date searched: 13 April 2022
Records retrieved: 2183

1 exp Coronary Artery Bypass/ (80577)
2 heart muscle revascularization/ (35206)
3 Heart Rehabilitation/ (13960)
4 cardiac rehab$.ti,ab. (12632)
5 (1 or 2) and (3 or 4) (1805)
6 exp Coronary Artery Bypass/rh (315)
7 heart muscle revascularization/rh (35)
8 coronary artery bypass graft$.ti,ab. (47309)
9 myocardial revascularization.ti,ab. (5742)
10 myocardial revascularisation.ti,ab. (575)
11 Heart Rehabilitation/ (13960)
12 cardiac rehab$.ti,ab. (12632)
13 (8 or 9 or 10) and (11 or 12) (871)
14 CABG.ti,ab. (35843)
15 Heart Rehabilitation/ (13960)
16 cardiac rehab$.ti,ab. (12632)
17 14 and (15 or 16) (733)
18 5 or 6 or 7 or 13 or 17 (2441)
19 limit 18 to english language (2183)

Key:
/ = indexing term (Emtree Subject Heading)
exp = exploded indexing term (Emtree)
/rh indexing term with rehabilitation subheading
$ = truncation
ti,ab,kw = terms in either title, abstract or keyword fields

Cochrane Central Register of Controlled Trials (CENTRAL)
via Wiley http://onlinelibrary.wiley.com/
Date range: Issue 3 of 12, March 2021
Date searched: 13 April 2022
Records retrieved: 194

#1	[mh "Coronary Artery Bypass"]	5605
#2	[mh "Cardiac Rehabilitation"]	316
#3	("cardiac rehab*"):ti,ab,kw	47
#4	#1 and (#2 or #3)	16
#5	[mh "Coronary Artery Bypass"/rh]	146
#6	[mh "Myocardial Revascularization"/rh]	176
#7	("coronary artery bypass graft*"):ti,ab,kw	5764
#8	("myocardial revascularization" or "myocardial revascularisation"):ti,ab,kw 1432	
#9	[mh "Cardiac Rehabilitation"]	316
#10	("cardiac rehab*"):ti,ab,kw	47
#11	(#7 or #8) and (#9 or #10)	24
#12	(CABG):ti,ab,kw	5900
#13	[mh "Cardiac Rehabilitation"]	316
#14	("cardiac rehab*"):ti,ab,kw	47
#15	#12 and (#13 or #14)	13
#16	#4 or #5 or #6 or #11 or #15 in Trials	194

Key:
mh = exploded indexing term (MeSH)
/rh = MeSH heading with rehabilitation subheading
* = truncation
ti,ab,kw = terms in either title or abstract or keyword fields

Appendix C

Comparing RCT Critical Appraisal Tools of PEDro to JBI

	RCT	Pedro Score/10	Pedro Score in Percentage	The Quality Based on Pedro	JBI Tool/13	JBI Normalized	The Quality Based On JBI
1	Hirschhorn et al. (2012)	9	90.0%	High Quality	9	69.0%	Moderate Quality
2	Hirschhornet al. (2008)	7	70.0%	High Quality	9	69.0%	Moderate Quality
3	Mendes et al. (2011)	5	50.0%	Moderate Quality	7	54.0%	Moderate Quality
4	Dong et al. (2016)	4	40.0%	Low Quality	4	31.0%	Low Quality
5	Ximenes et al. (2015)	4	40.0%	Low Quality	6	4.06%	Low Quality

Appendix D

STROBE Statement for Chapter 3

STROBE Statement—checklist of items that should be included in reports of observational studies

	Item No	Recommendation	Page No
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	-
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	-
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	62-63
Objectives	3	State specific objectives, including any prespecified hypotheses	63-64
Methods			
Study design	4	Present key elements of study design early in the paper	64
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	64-65
Participants	6	(*a*) *Cohort study*—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up *Case-control study*—Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls *Cross-sectional study*—Give the eligibility criteria, and the sources and methods of selection of participants	64-65
		(*b*) *Cohort study*—For matched studies, give matching criteria and number of exposed and unexposed *Case-control study*—For matched studies, give matching criteria and the number of controls per case	65-66
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	65-70
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	65-70
Bias	9	Describe any efforts to address potential sources of bias	64-70
Study size	10	Explain how the study size was arrived at	64
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	65-70
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	69-70
		(*b*) Describe any methods used to examine subgroups and interactions	69-70
		(*c*) Explain how missing data were addressed	69-70
		(*d*) *Cohort study*—If applicable, explain how loss to follow-up was addressed *Case-control study*—If applicable, explain how matching of cases and controls was addressed *Cross-sectional study*—If applicable, describe analytical methods taking account of sampling strategy	NA
		(*e*) Describe any sensitivity analyses	

Results

Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	70-71
		(b) Give reasons for non-participation at each stage	70-71
		(c) Consider use of a flow diagram	70-71
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	70-72
		(b) Indicate number of participants with missing data for each variable of interest	70-72
		(c) *Cohort study*—Summarise follow-up time (eg, average and total amount)	
Outcome data	15*	*Cohort study*—Report numbers of outcome events or summary measures over time	70-71
		Case-control study—Report numbers in each exposure category, or summary measures of exposure	
		Cross-sectional study—Report numbers of outcome events or summary measures	
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	83-88
		(*b*) Report category boundaries when continuous variables were categorised	65-70
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	83-88

Discussion

Key results	18	Summarise key results with reference to study objectives	83-88
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	96
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	88-96
Generalisability	21	Discuss the generalisability (external validity) of the study results	96

Other information

Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	-

Appendix E

The Cook's Distance Vs Leverage Plots to Examine Data for Cases with High Leverage for the Analysis in Chapter 3
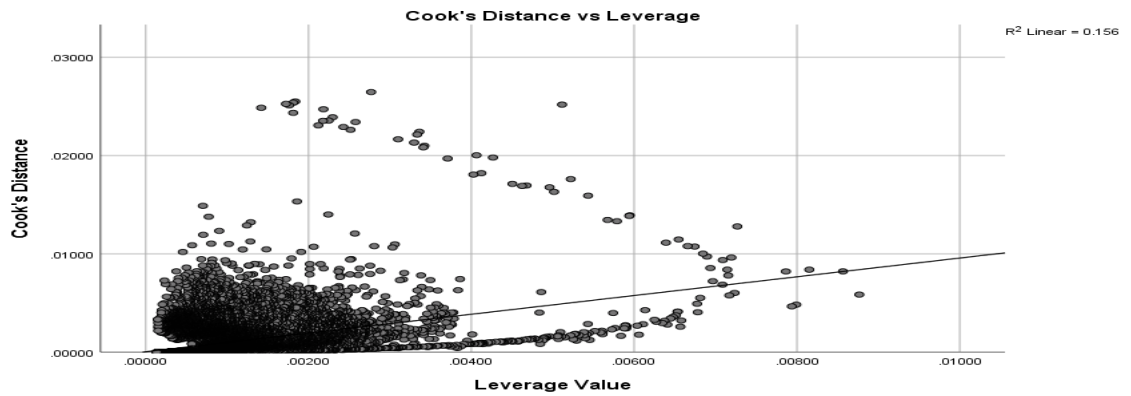
Figure E.1 Cook's Distance vs Leverage

The plot shows that having multicategory ethnicity variable would distort the analysis.
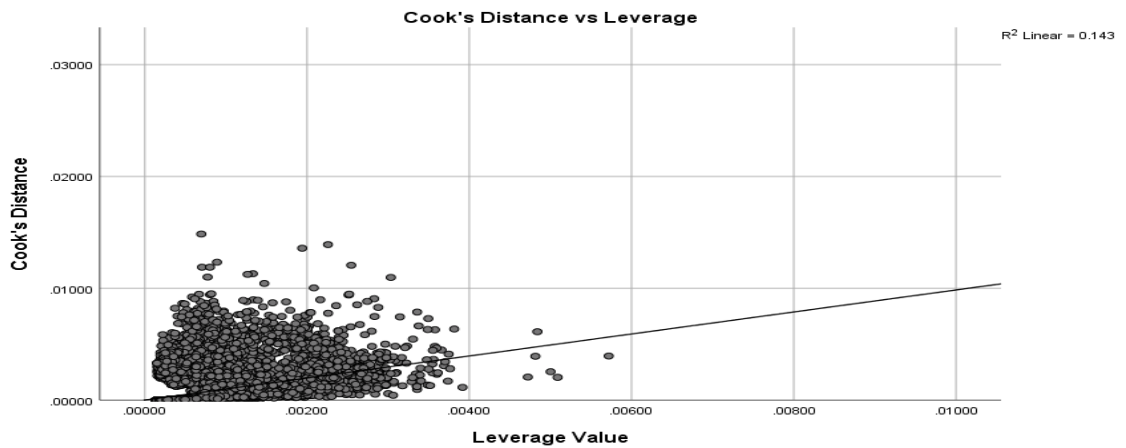
Figure E.2 Cook's Distance vs Leverage

The plot shows the improvement after transforming the ethnicity variable into a binary, it also shows the 6 cases with highest leverages values.
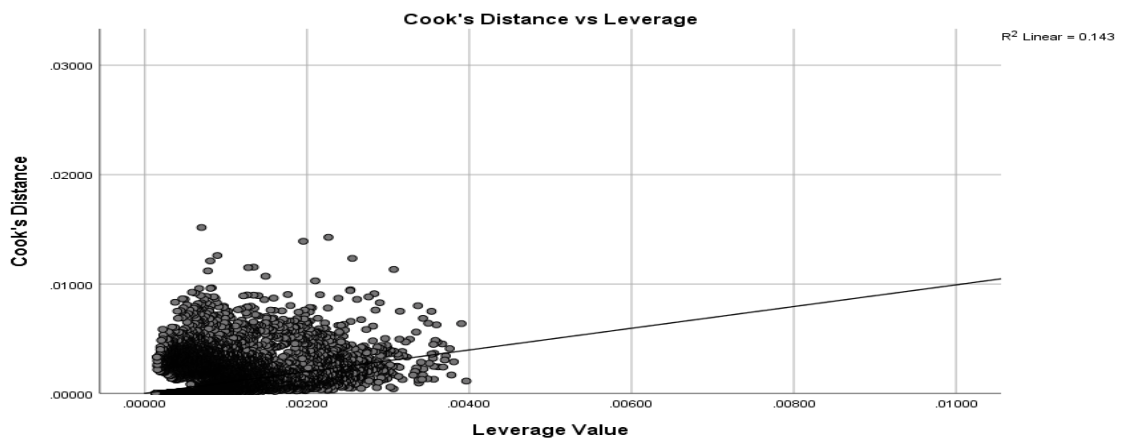
Figure E.3 Cook's Distance vs Leverage

The plot shows the distribution after examining and removing the 6 cases with highest leverage values.

Appendix F

Detailed Table for Chapter 3 Regression Analysis Outcomes

Factors (reference)		B	SE	*p-value	OR	1/ OR	95% CI	
							Lower	Upper
Treatment type (CABG)	Valve Surgeries	-0.133	0.034	<0.001	0.875	1.143	0.819	0.936
	CABG/valve	-0.122	0.046	0.009	0.885	1.130	0.808	0.970
waiting time (≤ 6 weeks WT)	> 6 weeks WT	0.936	0.030	<0.001	2.549	-	2.405	2.700
Gender (Male)	Female	-0.162	0.035	<0.001	0.851	1.175	0.795	0.911
Age (Mean centring)	In years	-0.012	0.002	<0.001	0.988	-	0.985	0.991
Gender* Age	-	-0.008	0.003	0.008	0.992	-	0.986	0.998
Ethnicity (White)	Non-white	0.103	0.046	0.026	1.108	-	1.012	1.213
SES (First Quintile)	Second quintile	0.165	0.050	<0.001	1.180	-	1.070	1.301
	Third quintile	0.306	0.049	<0.001	1.359	-	1.234	1.496
	Fourth quintile	0.274	0.048	<0.001	1.316	-	1.197	1.446
	Fifth quintile	0.511	0.048	<0.001	1.668	-	1.518	1.833
Previous CR (Previous CR)	No previous CR	1.015	0.082	<0.001	2.760	-	2.349	3.242
Partnership status (Not partnered)	Partnered	0.123	0.035	<0.001	1.131	-	1.056	1.211
Diabetes mellitus (No)	Yes	-0.149	0.033	<0.001	0.862	1.160	0.807	0.920
Family history of CVD (No)	Yes	0.257	0.034	<0.001	1.292	-	1.210	1.381
Hyperlipidaemia (No)	Yes	0.103	0.031	<0.001	1.109	-	1.044	1.178
Previous cardiac events (No)	Yes, for Previous events	-0.298	0.029	<0.001	0.742	1.348	0.701	0.786
Hospital length of stay (≤ 6 days)	7-9 days	0.066	0.039	0.090	1.069	-	0.990	1.154
	10-17 days	-0.084	0.040	0.034	0.920	1.087	0.851	0.994
	≥18 days	-0.109	0.040	0.007	0.896	1.116	0.828	0.970
Confirmed joining date (No)	Yes	1.335	0.030	<0.001	3.798	-	3.584	4.025

* Significant if p-value < 0.05.

Note: Not significant variables (angina, hypertension, anxiety, hyperlipidaemia, number of comorbidities, a diagnosis of ≥ 2 cardiac events

SE: Standard error. AMI: Acute myocardial infarction. CABG: coronary artery bypass grafting. CR: cardiac rehabilitation. CVD: cardiovascular disease. PCI: percutaneous coronary intervention. WT: waiting time. OR: odds ratio. CI: confident intervals. SES: socioeconomic status.

Appendix G
Unadjusted Odds Ratios for Chapter 3 Regression Analysis Outcomes

Factors (reference)		p-value*	OR	95% CI	
				Lower	Upper
Treatment type (CABG)	**Valve Surgeries**	<0.001	0.830	0.805	0.857
	CABG/valve	<0.001	0.838	0.800	0.878
Waiting time (WT ≤ 2 weeks)	**2 > WT ≤ 4 weeks**	<0.001	2.388	2.285	2.495
	4 > WT ≤ 6 weeks	<0.001	4.958	4.723	5.205
	6 > WT ≤ 8 weeks	<0.001	7.032	6.673	7.411
	WT > 8 weeks	<0.001	5.627	5.394	5.870
Waiting time (≤ 6 weeks WT)	**> 6 weeks WT**	<0.001	0.387	0.376	0.399
Waiting time	**In weeks**	<0.001	1.122	1.117	1.126
Age (Mean centring)	**In years**	<0.001	0.990	0.989	0.991
Gender (Male)	**Female**	<0.001	0.790	0.764	0.816
Gender* Age	**-**	<0.001	0.981	0.978	0.983
Ethnicity (White)	**Non-white**	0.754	1.008	0.961	1.057
Previous CR (Previous CR)	**No previous CR**	<0.001	2.809	2.591	3.045
SES (First quintile most deprived)	**Second quintile**	<0.001	1.136	1.075	1.199
	Third quintile	<0.001	1.267	1.202	1.336
	Fourth quintile	<0.001	1.353	1.284	1.425
	Fifth quintile	<0.001	1.569	1.489	1.652
Partnership status (Not partnered)	**Partnered**	<0.001	1.239	1.188	1.293
Angina (No)	**Yes**	0.022	0.947	0.904	0.992
Diabetes mellitus (No)	**Yes**	<0.001	0.848	0.814	0.884
Hypertension (No)	**Yes**	<0.001	0.909	0.877	0.943
Anxiety (No)	**Yes**	<0.001	1.289	1.177	1.411
Depression (No)	**Yes**	<0.001	1.182	1.088	1.284
Family history of CVD (No)	**Yes**	<0.001	1.309	1.253	1.367
Hyperlipidaemia (No)	**Yes**	<0.001	1.164	1.120	1.209
Number of comorbidities (No comorbidity)	**1-2 comorbidities**	<0.001	1.185	1.068	1.315
	≥ 3 comorbidities	<0.001	0.925	0.891	0.960
A diagnosis of ≥ 2 cardiac events	**CABG and/or valve plus AMI**	0.087	0.870	0.742	1.020
	CABG and/or valve plus PCI	0.073	0.861	0.731	1.014
	CABG and/or valve plus AMI + PCI	0.148	0.818	0.623	1.074
Hospital length of stay (≤ 6 days)	**7-9 days**	0.884	0.997	0.954	1.041
	10-17 days	<0.001	0.866	0.828	0.905
	≥18 days	<0.001	0.893	0.855	0.933
Confirmed joining date (No)	**Yes**	<0.001	3.040	2.950	3.132
Previous cardiac events (No)	**Yes**	<0.001	1.193	1.157	1.231

* Significant if p-value < 0.05.

AMI: Acute myocardial infarction. CABG: coronary artery bypass grafting. CR: cardiac rehabilitation. CVD: cardiovascular disease. PCI: percutaneous coronary intervention. WT: waiting time. OR: odds ratio. CI: confident intervals. SES: socioeconomic status.

Appendix H

STROBE Statement for Chapter 4

STROBE Statement—checklist of items that should be included in reports of observational studies

	Item No	Recommendation	Page No
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	-
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	-
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	97-99
Objectives	3	State specific objectives, including any prespecified hypotheses	99
Methods			
Study design	4	Present key elements of study design early in the paper	99
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	99-100
Participants	6	(*a*) *Cohort study*—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up *Case-control study*—Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls *Cross-sectional study*—Give the eligibility criteria, and the sources and methods of selection of participants	99-100
		(*b*) *Cohort study*—For matched studies, give matching criteria and number of exposed and unexposed *Case-control study*—For matched studies, give matching criteria and the number of controls per case	
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	100-102
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	99-100
Bias	9	Describe any efforts to address potential sources of bias	99-100
Study size	10	Explain how the study size was arrived at	99-100
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	100-102
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	102-103
		(*b*) Describe any methods used to examine subgroups and interactions	102-103
		(*c*) Explain how missing data were addressed	102-103
		(*d*) *Cohort study*—If applicable, explain how loss to follow-up was addressed *Case-control study*—If applicable, explain how matching of cases and controls was addressed *Cross-sectional study*—If applicable, describe analytical methods taking account of sampling strategy	NA
		(*e*) Describe any sensitivity analyses	

Results

Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	104
		(b) Give reasons for non-participation at each stage	104
		(c) Consider use of a flow diagram	104
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	104-111
		(b) Indicate number of participants with missing data for each variable of interest	111-112
		(c) *Cohort study*—Summarise follow-up time (eg, average and total amount)	
Outcome data	15*	*Cohort study*—Report numbers of outcome events or summary measures over time	105-112
		Case-control study—Report numbers in each exposure category, or summary measures of exposure	
		Cross-sectional study—Report numbers of outcome events or summary measures	
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	112-121
		(*b*) Report category boundaries when continuous variables were categorised	101-102
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	-

Discussion

Key results	18	Summarise key results with reference to study objectives	121-133
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	134
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	121-133
Generalisability	21	Discuss the generalisability (external validity) of the study results	134

Other information

Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	-

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Appendix I

The Independent 21 Variables with Missing Data for Chapter 4 Analysis

	Factors with missing data	Missing Count	missing percentage
1	Referring health professional	2,767	8.6%
2	Hospital length of stay	4,051	12.5%
3	Smoking	6,317	19.5%
4	Angina	6,503	20.1%
5	Diabetes	6,503	20.1%
6	Hypertension	6,503	20.1%
7	Anxiety	6,503	20.1%
8	Depression	6,503	20.1%
9	Family history of CVD	6,503	20.1%
10	Hyperlipidaemia	6,503	20.1%
11	Number of comorbidities	6,503	20.1%
12	CR delivery mode	7,104	22.0%
13	BMI	7,286	22.5%
14	Employment status	9,350	28.9%
15	Physical activity (150 min/week)	9,835	30.4%
16	HADS-Anxiety	10,405	32.2%
17	HADS-Depression	10,414	32.2%
18	Social Support	11,423	35.3%
19	Referral Source	11,551	35.7%
20	Alcohol consumption	12,663	39.2%
21	History of CABG	14,683	45.4%

Appendix J

Unadjusted Odds Ratios for Chapter 4 Regression Analysis Outcomes

Factors (reference)		p-value*	OR	95% CI	
				Lower	Upper
Treatment type (CABG)	Valve Surgeries	<0.001	0.877	0.825	0.932
	CABG/valve	0.375	0.959	0.874	1.052
Waiting time (≤ 6 weeks WT)	> 6 weeks WT	0.078	0.952	0.900	1.006
Age (Mean centring)	In years	<0.001	1.015	1.012	1.017
Gender (Male)	Female	<0.001	0.844	0.791	0.900
Gender* Age	-	<0.001	1.009	1.007	1.011
Ethnicity (White)	Non-white	0.005	0.890	0.820	0.966
Previous CR (Previous CR)	No previous CR	0.008	1.302	1.070	1.585
SES (First quintile most deprived)	Second quintile	<0.001	1.326	1.203	1.463
	Third quintile	<0.001	1.484	1.351	1.631
	Fourth quintile	<0.001	1.702	1.551	1.868
	Fifth quintile	<0.001	1.848	1.690	2.022
Partnership status (Not partnered)	Partnered	<0.001	1.381	1.294	1.474
Angina (No)	Yes	0.318	1.038	0.964	1.118
Diabetes mellitus (No)	Yes	<0.001	0.825	0.746	0.913
Hypertension (No)	Yes	0.392	1.028	0.965	1.096
Anxiety (No)	Yes	0.161	0.823	0.619	1.093
Depression (No)	Yes	0.073	0.710	0.485	1.039
Family history of CVD (No)	Yes	0.923	1.004	0.931	1.082
Hyperlipidaemia (No)	Yes	0.015	1.077	1.015	1.144
A history of previous (CABG) (No)	Yes	0.428	0.885	0.641	1.221
Number of comorbidities (No comorbidity)	1-2 comorbidities	0.919	0.992	0.838	1.174
	≥ 3 comorbidities	0.065	0.866	0.742	1.009
A diagnosis of ≥ 2 cardiac events (CABG or/and valve surgeries)	CABG and/or valve plus AMI	0.173	0.948	0.877	1.024
	CABG and/or valve plus PCI	0.037	0.659	0.445	0.976
	CABG and/or valve plus AMI + PCI	0.078	0.790	0.609	1.026
Hospital length of stay (≤ 6 days)	7-9 days	0.128	0.937	0.862	1.019
	10-16 days	<0.001	0.855	0.791	0.923
	≥ 17 days	<0.001	0.877	0.813	0.946
Confirmed joining date (No)	Yes	<0.001	1.243	1.164	1.327
Previous cardiac events (No)	Yes	<0.001	0.874	0.826	0.924
Smoking (No)	Yes	<0.001	0.501	0.424	0.591
BMI** (< 30 kg/m^2)	≥ 30 kg/m^2	<0.001	0.800	0.748	0.857
Physical activity (150 min/week) No)	Yes	<0.001	1.216	1.143	1.294
Employment (Employed)	Unemployed	<0.001	0.837	0.761	0.921
	Retired	0.021	1.090	1.013	1.172
HADS-Anxiety (Normal)	Borderline/clinically anxious	<0.001	0.783	0.726	0.845
HADS-Depression (Normal)	Borderline/clinically depressed	<0.001	0.745	0.690	0.805
Social support (No)	Yes	0.026	1.170	1.019	1.343
Alcohol consumption (No)	Yes	0.264	0.948	0.862	1.042
CR delivery mode (Supervised delivery)	Self-delivery CR	0.010	0.891	0.817	0.972

Factors (reference)		p-value*	OR	95% CI	
				Lower	Upper
Referring health professional (Consultant/cardiac nurse)	**GP/primary care nurse**	0.405	1.092	0.887	1.346
	others	<0.001	1.219	1.112	1.337
Referral Source (Private Hospital)	**GP/NHS Trust**	1.000	1.000	0.851	1.175
Multidisciplinary team (No)	**Yes**	0.234	0.959	0.896	1.027
BACPR certified programme (No)	**Yes**	0.094	0.952	0.899	1.008

* Significant if p-value < 0.05.

AMI: Acute myocardial infarction. CABG: coronary artery bypass grafting. CR: cardiac rehabilitation. CVD: cardiovascular disease. PCI: percutaneous coronary intervention. WT: waiting time. BMI**: Body mass index . HADS: Hospital Anxiety and Depression Scale. WT: waiting time. BACPR: British Association for Cardiovascular Prevention and Rehabilitation. GP: General Practitioner. OR: odds ratio. CI: confident intervals. SES: socioeconomic status.

Appendix K

List of Chapter 5 Hypotheses

CR outcomes		H0 (null)	H1 (experimental)
Psychological health factors outcomes	**Obesity**	Waiting time factor has no association with the cardiovascular risk factor outcome of obesity	Waiting time factor has an association with the cardiovascular risk factor outcome of obesity.
	Smoking	Waiting time factor has no association with the cardiovascular risk factor outcome of smoking.	Waiting time factor has an association with the cardiovascular risk factor outcome of smoking.
	Physical activity-(150 min/week)	Waiting time factor has no association with the cardiovascular risk factor outcome of physical activity-(150 min/week)	Waiting time factor has an association with of the cardiovascular risk factor outcome of physical activity-(150 min/week)
	Blood pressure	Waiting time factor has no association with the cardiovascular risk factor outcome of blood pressure	Waiting time factor has an association with of the cardiovascular risk factor outcome of blood pressure
Psychological health outcomes	**HADS-Anxiety**	Waiting time factor has no association with the psychological health outcomes of HADS-Anxiety	Waiting time factor has an association with of the psychological health outcomes of HADS-Anxiety
	HADS-Depression	Waiting time factor has no association with the psychological health outcomes of HADS-Depression	Waiting time factor has an association with of the psychological health outcomes of HADS-Depression
	Feelings (Dartmouth)	Waiting time factor has no association with the psychological health outcomes of feelings (Dartmouth)	Waiting time factor has an association with of the psychological health outcomes of feelings (Dartmouth)
	QOL (Dartmouth)	Waiting time factor has no association with the psychological health outcomes of QOL (Dartmouth)	Waiting time factor has an association with of the psychological health outcomes of QOL (Dartmouth)
Physical fitness factor outcome	**Physical fitness (Dartmouth)**	Waiting time factor has no association with the physical fitness factor outcome of physical fitness (Dartmouth)	Waiting time factor has an association with of the physical fitness factor outcome of physical fitness (Dartmouth)
	6MWT	Waiting time factor has no association with the physical fitness factor outcome of 6MWT	Waiting time factor has an association with of the physical fitness factor outcome of 6MWT
	ISWT	Waiting time factor has no association with the physical fitness factor outcome of ISWT	Waiting time factor has an association with of the physical fitness factor outcome of ISWT

Appendix L

STROBE Statement for Chapter 5

STROBE Statement—checklist of items that should be included in reports of observational studies

	Item No	Recommendation	Page No
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	-
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	-
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	136-137
Objectives	3	State specific objectives, including any prespecified hypotheses	137-138
Methods			
Study design	4	Present key elements of study design early in the paper	138
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	138-139
Participants	6	(*a*) *Cohort study*—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up	138-139
		Case-control study—Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls	
		Cross-sectional study—Give the eligibility criteria, and the sources and methods of selection of participants	
		(*b*) *Cohort study*—For matched studies, give matching criteria and number of exposed and unexposed	
		Case-control study—For matched studies, give matching criteria and the number of controls per case	
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	139-141
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	139-141
Bias	9	Describe any efforts to address potential sources of bias	141-142
Study size	10	Explain how the study size was arrived at	141-142
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	141-142
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	141-142
		(*b*) Describe any methods used to examine subgroups and interactions	141-142
		(*c*) Explain how missing data were addressed	141-142
		(*d*) *Cohort study*—If applicable, explain how loss to follow-up was addressed	NA

		Case-control study—If applicable, explain how matching of cases and controls was addressed *Cross-sectional study*—If applicable, describe analytical methods taking account of sampling strategy	
		(*e*) Describe any sensitivity analyses	

Results

Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	142
		(b) Give reasons for non-participation at each stage	142
		(c) Consider use of a flow diagram	142
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	144-173
		(b) Indicate number of participants with missing data for each variable of interest	144-173
		(c) *Cohort study*—Summarise follow-up time (eg, average and total amount)	
Outcome data	15*	*Cohort study*—Report numbers of outcome events or summary measures over time	144-173
		Case-control study—Report numbers in each exposure category, or summary measures of exposure	
		Cross-sectional study—Report numbers of outcome events or summary measures	
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	144-173
		(*b*) Report category boundaries when continuous variables were categorised	144-173
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	-

Discussion

Key results	18	Summarise key results with reference to study objectives	173
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	173-184
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	173-184
Generalisability	21	Discuss the generalisability (external validity) of the study results	185

Other information

Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	-

Appendix M

Multicategorical Variables Transformed into Dichotomous Dummy Variables for Linear Regression Analysis

Multicategorical variables	Reference variable	dichotomous dummy variables
Age	**(18-60 years old)**	61-67 years old (0, 1)
		68-73 years old (0, 1)
		74-100 years old (0, 1)
Treatment type	**CABG**	Valve Surgery (0, 1)
		CABG/valve (0, 1)
SSE	**First quintile**	Second quintile (0, 1)
		Third quintile (0, 1)
		Fourth quintile (0, 1)
		Fifth quintile (0, 1)
Hospital length of stay	**≤ 6 days**	7-9 days (0, 1)
		10-16 days (0, 1)
		more than 16 days (0, 1)
Number of comorbidities	**no comorbidity**	1-2 comorbidities (0, 1)
		≥ 3 comorbidities (0, 1)
A diagnosis of ≥ 2 cardiac events	**CABG or/and valve surgeries**	CABG or/and valve surgeries plus AMI (0, 1)
		CABG or/and valve surgeries plus PCI (0, 1)
		CABG or/and valve surgeries plus AMI/PCI (0, 1)
Referring health professional	**consultant/cardiac nurse**	GP/primary care nurse (0, 1)
		Other (0, 1)

Appendix N

The Logistic Regression 5 Blocks for Obesity in Chapter 5

The Regression Blocks	Factors	−2 Log likelihood	Nagelkerke R^2	Overall Model accuracy
Block 1	**BMI pre-CR**	5,849.458	0.737	94.1
	waiting time			
Block 2	**Treatment type**	5,740.108	0.744	94.1
	Age			
	Gender			
	Ethnicity			
	Partnership status			
	SES			
	Previous CR			
Block 3	**Hospital length of stay**	5,708.247	0.745	94.1
	Angina			
	Diabetes mellitus			
	Hypertension			
	Anxiety			
	Depression			
	Family history of CVD			
	Hyperlipidaemia			
	Number of comorbidities			
	A diagnosis of ≥ 2 cardiac events			
	Confirmed joining date			
Block 4	**Referring health professional**	5,708.247	0.745	94.1
	CR delivery mode			
Block 5	**Multidisciplinary team**	5,708.247	0.745	94.1
	BACPR certified programme			

Appendix O

The Logistic Regression 5 Blocks for Smoking in Chapter 5

The Regression Blocks	Factors	−2 Log likelihood	Nagelkerke R^2	Overall Model accuracy
Block 1	Smoking pre-CR	1,503.999	0.463	98.2
	waiting time			
Block 2	Treatment type	1,499.742	0.465	98.2
	Age			
	Gender			
	Ethnicity			
	Partnership status			
	SES			
	Previous CR			
Block 3	Hospital length of stay	1,492.738	0.468	98.1
	Angina			
	Diabetes mellitus			
	Hypertension			
	Anxiety			
	Depression			
	Family history of CVD			
	Hyperlipidaemia			
	Number of comorbidities			
	A diagnosis of ≥ 2 cardiac events			
	Confirmed joining date			
Block 4	Referring health professional	1,463.321	0.479	98.6
	CR delivery mode			
Block 5	Multidisciplinary team	1,463.321	0.479	98.6
	BACPR certified programme			

Appendix P

The Logistic Regression 5 Blocks for Physical activity (150 min/week) in Chapter 5

The Regression Blocks	Factors	−2 Log likelihood	Nagelkerke R^2	Overall Model accuracy
Block 1	Physical activity (150 min/week) pre-CR	11,395.441	0.129	78.8
	waiting time			
Block 2	Treatment type	11,326.021	0.137	78.8
	Age			
	Gender			
	Ethnicity			
	Partnership status			
	SES			
	Previous CR			
Block 3	Hospital length of stay	11,255.023	0.145	78.8
	Angina			
	Diabetes mellitus			
	Hypertension			
	Anxiety			
	Depression			
	Family history of CVD			
	Hyperlipidaemia			
	Number of comorbidities			
	A diagnosis of ≥ 2 cardiac events			
	Confirmed joining date			
Block 4	Referring health professional	11,243.608	0.147	78.9
	CR delivery mode			
Block 5	Multidisciplinary team	11,238.456	0.147	78.8
	BACPR certified programme			

Appendix Q

The Logistic Regression 5 Blocks for Blood pressure in Chapter 5

The Regression Blocks	Factors	−2 Log likelihood	Nagelkerke R^2	Overall Model accuracy
Block 1	Blood pressure pre-CR	15,916.426	0.171	72.3
	waiting time			
Block 2	Treatment type	15,586.621	0.199	72.2
	Age			
	Gender			
	Ethnicity			
	Partnership status			
	SES			
	Previous CR			
Block 3	Hospital length of stay	15,390.220	0.216	72.8
	Angina			
	Diabetes mellitus			
	Hypertension			
	Anxiety			
	Depression			
	Family history of CVD			
	Hyperlipidaemia			
	Number of comorbidities			
	A diagnosis of ≥ 2 cardiac events			
	Confirmed joining date			
Block 4	Referring health professional	15,390.220	0.216	72.8
	CR delivery mode			
Block 5	Multidisciplinary team	15,385.317	0.216	72.6
	BACPR certified programme			

Appendix R

The Logistic Regression 5 Blocks for Anxiety in Chapter 5

The Regression Blocks	Factors	−2 Log likelihood	Nagelkerke R²	Overall Model accuracy
Block 1	**Pre-CR HADS-Anxiety**	7,969.908	0.306	84.4
	waiting time			
Block 2	**Treatment type**	7,857.367	0.320	84.9
	Age			
	Gender			
	Ethnicity			
	Partnership status			
	SES			
	Previous CR			
Block 3	**Hospital length of stay**	7,797.805	0.327	85.2
	Angina			
	Diabetes mellitus			
	Hypertension			
	Anxiety			
	Depression			
	Family history of CVD			
	Hyperlipidaemia			
	Number of comorbidities			
	A diagnosis of ≥ 2 cardiac events			
	Confirmed joining date			
Block 4	**Referring health professional**	7,797.805	0.327	85.2
	CR delivery mode			
Block 5	**Multidisciplinary team**	7,797.805	0.327	85.2
	BACPR certified programme			

Appendix S

The Logistic Regression 5 Blocks for Depression in Chapter 5

The Regression Blocks	Factors	−2 Log likelihood	Nagelkerke R²	Overall Model accuracy
Block 1	**Pre-CR HADS-Depression**	5,638.248	0.252	90.5
	waiting time			
Block 2	**Treatment type**	5,527.645	0.270	90.6
	Age			
	Gender			
	Ethnicity			
	Partnership status			
	SES			
	Previous CR			
Block 3	**Hospital length of stay**	5,444.744	0.284	90.6
	Angina			
	Diabetes mellitus			
	Hypertension			
	Anxiety			
	Depression			
	Family history of CVD			
	Hyperlipidaemia			
	Number of comorbidities			
	A diagnosis of ≥ 2 cardiac events			
	Confirmed joining date			
Block 4	**Referring health professional**	5,434.794	0.286	90.7
	CR delivery mode			
Block 5	**Multidisciplinary team**	5,434.794	0.286	90.7
	BACPR certified programme			

Appendix T

The Logistic Regression 5 Blocks for Feelings (Dartmouth) in Chapter 5

The Regression Blocks	Factors	−2 Log likelihood	Nagelkerke R^2	Overall Model accuracy
Block 1	Feelings (Dartmouth) pre-CR	4,574.632	0.146	92.6
	waiting time			
Block 2	Treatment type	4,499.366	0.164	92.6
	Age			
	Gender			
	Ethnicity			
	Partnership status			
	SES			
	Previous CR			
Block 3	Hospital length of stay	4,432.940	0.179	92.6
	Angina			
	Diabetes mellitus			
	Hypertension			
	Anxiety			
	Depression			
	Family history of CVD			
	Hyperlipidaemia			
	Number of comorbidities			
	A diagnosis of ≥ 2 cardiac events			
	Confirmed joining date			
Block 4	Referring health professional	4,432.940	0.179	92.6
	CR delivery mode			
Block 5	Multidisciplinary team	4,432.940	0.179	92.6
	BACPR certified programme			

Appendix U

The Logistic Regression 5 Blocks for QOL (Dartmouth) in Chapter 5

The Regression Blocks	Factors	−2 Log likelihood	Nagelkerke R^2	Overall Model accuracy
Block 1	QOL (Dartmouth) pre-CR	1,543.003	0.056	98.4
	waiting time			
Block 2	Treatment type	1,524.887	0.068	98.4
	Age			
	Gender			
	Ethnicity			
	Partnership status			
	SES			
	Previous CR			
Block 3	Hospital length of stay	1,479.943	0.098	98.4
	Angina			
	Diabetes mellitus			
	Hypertension			
	Anxiety			
	Depression			
	Family history of CVD			
	Hyperlipidaemia			
	Number of comorbidities			
	A diagnosis of ≥ 2 cardiac events			
	Confirmed joining date			
Block 4	Referring health professional	1,479.943	0.098	98.4
	CR delivery mode			
Block 5	Multidisciplinary team	1,475.013	0.101	98.4
	BACPR certified programme			

Appendix V

The Logistic Regression 5 Blocks for Physical fitness (Dartmouth) in Chapter 5

The Regression Blocks	Factors	−2 Log likelihood	Nagelkerke R^2	Overall Model accuracy
Block 1	Physical fitness (Dartmouth) pre-CR	9,751.895	0.110	77.6
	waiting time			
Block 2	Treatment type	9,243.298	0.181	77.9
	Age			
	Gender			
	Ethnicity			
	Partnership status			
	SES			
	Previous CR			
Block 3	Hospital length of stay	9,152.362	0.193	78.0
	Angina			
	Diabetes mellitus			
	Hypertension			
	Anxiety			
	Depression			
	Family history of CVD			
	Hyperlipidaemia			
	Number of comorbidities			
	A diagnosis of ≥ 2 cardiac events			
	Confirmed joining date			
Block 4	Referring health professional	9,138.126	0.195	77.9
	CR delivery mode			
Block 5	Multidisciplinary team	9,138.126	0.195	77.9
	BACPR certified programme			

Appendix W

Examining the Assumptions of the Linear Regression Model for 6MWT

The assumptions of the linear regression model were examined.

- Inspecting the regression standardised residual versus regression standardised predicted scatter plot (see Figure X.1), it seems that the assumptions of linearity and homoscedasticity were not violated.

- As all VIF < 10 and tolerance > 0.1, the assumption of absence of multicollinearity was met.

- The assumption of normality was met after examining the p-p plot (see Figure X.2). Since Durbin–Watson= 1.947, it can be assumed that there is an independent error.

- While there were no unusual cases were found when the cook's distance was examining. However, investigate the scatter plot of regression standardised residual versus regression standardised predicted would show 21 cases beyond ± 3, in addition to 6 unusual cases which were (> 0.17) extremely higher than the cut-off points for centred leverage = 0.0352. To test if the 27 unusual observations had decreased the model fit, they were filtered out, and the regression model was run again. the result of the analysis of variance was $F_{(35,1635)} = 153.381$, p-value < 0.001 and $R^2 = 0.767$, which mean that 77.0% of the variance in the 6MWT post-CR could be explained by the model which is an improvement from the first run. Reviewing the linear regression assumptions again showed none were violated; in fact, it yielded improved normality (see Figure X.3). Since filtering out the 27 observations improved the model, they were excluded.
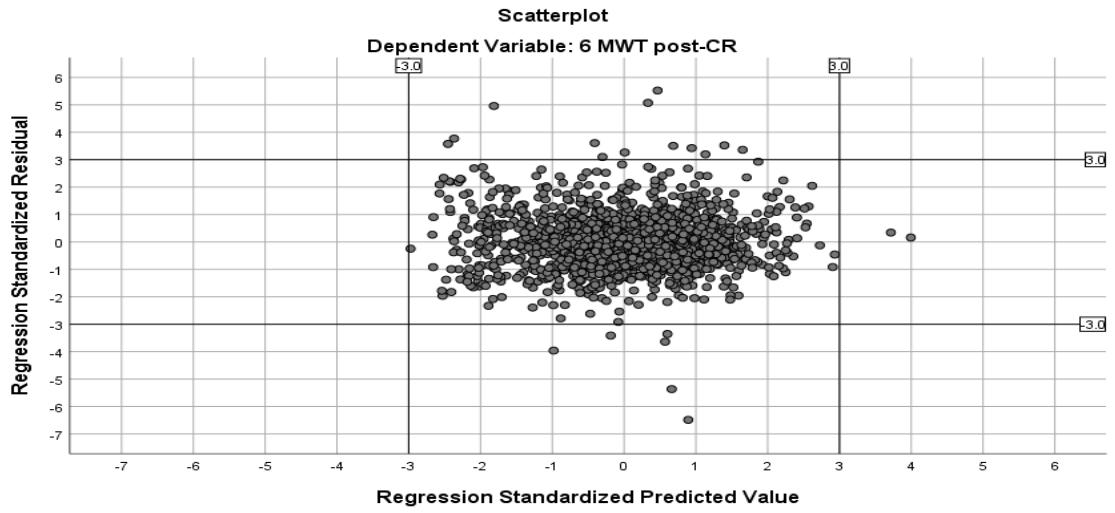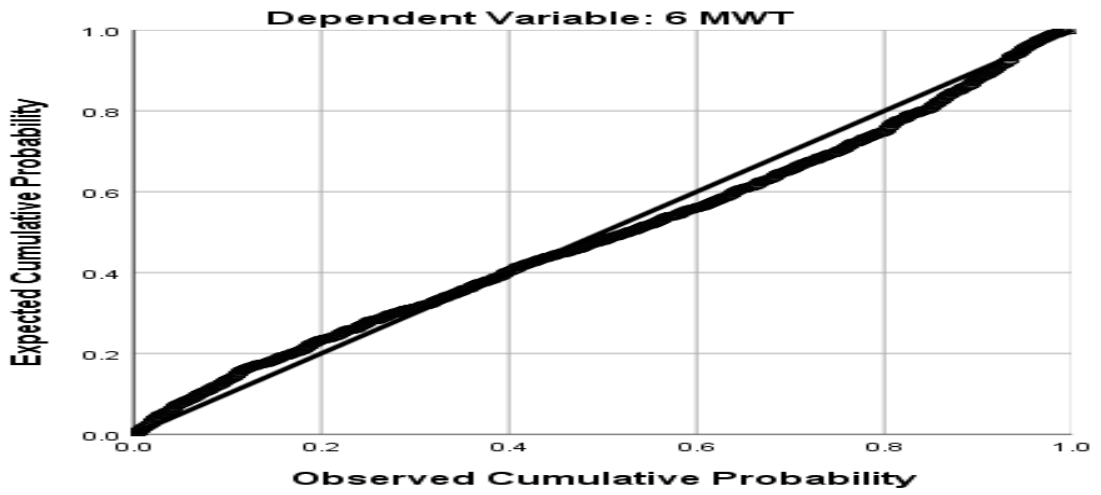
Figure W.1 Scatter plot of standardized residuals

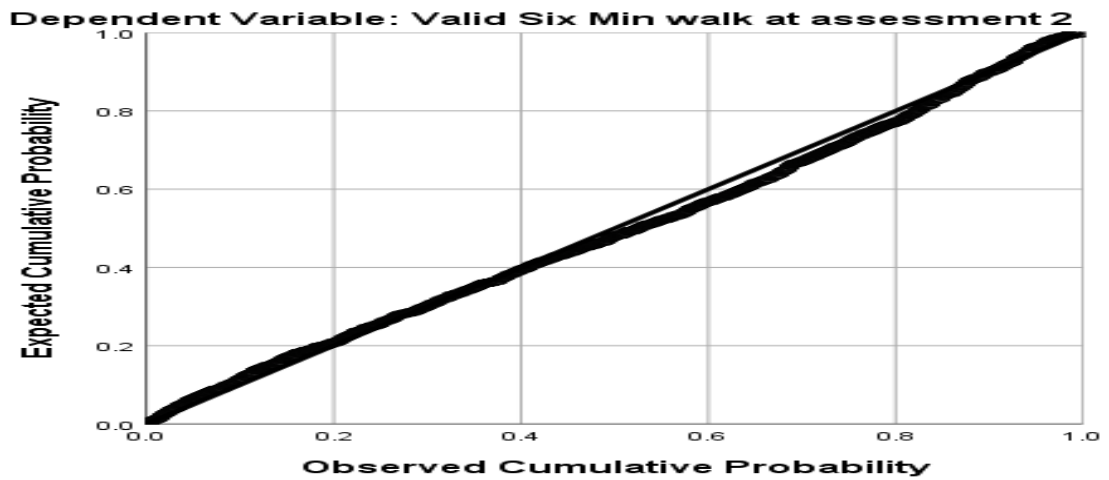

Figure W.2 P-P Plot of regression standardized residuals

Figure W.3 P-P Plot of regression standardized residuals

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